Growth Response of Rose Geranium (*Pelargonium graveolens* L.) to Calcium:Magnesium Ratio, Magnetic Field, and Mycorrhizae

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Abstract. The objective of this study was to evaluate the effects of the Ca:Mg ratio, magnetic field (MF), and mycorrhizal amendment on the yield and mineral composition of rose geranium. The experiment was structured as a 3×2 factorial experimental design, with three levels of the Ca:Mg ratio (2.40:6.78, 4.31:4.39, and 6.78:2.40 meq·L⁻¹), 6.78 Ca:2.40 Mg meq·L⁻¹ denoted by “High-Ca:Low-Mg,” equal proportion of Ca and Mg (4.31 Ca:4.39 Mg meq·L⁻¹) represented by “EP-Ca:Mg,” and 2.32 Ca:6.38 Mg meq·L⁻¹ denoted by “Low-Ca:High-Mg,” two levels of MF (no MF, denoted by “0 MF,” and 110 mT, denoted by “1 MF”) and split treatments of mycorrhizae (zero mycorrhizae denoted by “0 Myco,” and 20 mL mycorrhizae denoted by “1 Myco”) were used in this study. The results show that the plant height and branch dry mass were significantly ($P < 0.05$) affected by the Ca:Mg ratio. No significant effect of Ca:Mg ratio, MF, or mycorrhizae on the number of leaves, foliar mass, leaf dry mass, or yield was detected. Phosphorus, K, S, Fe, and B accumulation in the stem were unaffected, as were leaf N, P, K, Ca, S, Fe, and Cu. However, some agronomic attributes (plant height, number of branches, root length, and chlorophyll content) and mineral composition (Stem-N) were optimized when the 1 MF exposed nutrient solution was used with about equal proportions of Ca and Mg. This Ca:Mg ratio in the nutrient solution, together with the exposure of rose geranium plants to 1 MF, yielded positive results. The findings of this study can be applied to improve the production of rose geranium by enhancing the growth and mineral concentration of this crop.

The fundamental goal of applying fertilizers is to supply nutrients that are essential for crop growth and increased yield. Crop yield is the basic factor that determines optimal fertilization (Ju and Christie, 2011). Therefore, it is important to apply fertilizers in an efficient way to minimize loss and to improve the nutrient use efficiency of crops (Yousaf et al., 2017). Correct application of nutrients may enhance crop quality, but oversupply can have harmful effects. For instance, oversupply of certain nutrients leads to reduction of seed formation by encouraging excessive vegetative growth (Patel et al., 2015). Mengel and Kirkby (2004) reported that fertilizer applied during the vegetative

stage must be well balanced to provide nutrition for optimum growth of the plant.

Rose geranium responds well to nutrient application, but the response varies with time and the growth stage of the application (Alveiro et al., 2017; Araya, 2012). In addition, if the crop requirements are not met, shortages will have a negative impact on rose geranium oil yield and quality (Araya, 2012). For instance, lack of nitrogen leads to poor yield and reduced chlorophyll content of rose geranium (Sedibe and Allemann, 2012; Welch et al., 1993). Nonetheless, rose geranium may require application of a well-balanced fertilizer, especially in fertigation systems (Sedibe, 2012). Rose geranium responds well to N, P, and K application (Araya et al., 2006; Sedibe, 2012). Among the essential elements, Ca and Mg play the most important roles in improving the quantitative and qualitative agronomic attributes of crops grown in greenhouses or under field conditions.

Calcium plays an important role in the physiological development of plants influencing cell elongation, cell maturation, meristematic tissue development, and protein

synthesis. Calcium is also required for the stability and functions of cell walls (White and Broadly, 2003). Inadequate application of Ca has a negative impact on plants, leading to the collapse of cell walls (Sander and Andren, 1997).

Similarly, adequate Mg nutrition is required for root and shoot growth, in terms of biosynthesis and translocation of photo assimilates. Magnesium plays a critical role in phloem loading and transportation of photo assimilates into sink organs (Zhang and Turgeon, 2009). Plants with low Mg supply are very sensitive to light intensity and heat stress and can easily become chlorotic and necrotic, probably because of extensive production of reactive oxygen (Cakmak and Kirkby, 2008). There is limited information available on the effect that the Ca:Mg ratio has on rose geranium production.

Biostimulation of crops with the external application of an MF as a way to improve plant physiology, as well as oil quantity and oil composition to meet geranium bourbon essential oil standards, has caught the interest of many scientists around the world. External MF application for the purpose of nutrient modification in microorganisms and biological systems is becoming an increasingly important technique as new evidence reveals the ability of plants and microorganisms to perceive and respond quickly to MF (Kordas, 2002; Occhipinti et al., 2014; Vanderstraeten, and Burda, 2012). However, the biological effects of MF treatments depend on the strength and exposure period of the plant to the MF. The interaction of an MF and exposure time indicate that a certain combination of MF and duration are highly effective in enhancing growth characteristics. However, there is still no clear indication of how MFs achieve such changes.

There is also a growing interest from hydroponic rose growers in biologically based approaches to plant production to reduce the utilization of high amounts of fertilizers and pesticides. Various studies have shown that application of mycorrhizae can improve growth and yield through improved nutrient uptake, particularly under conditions of limited water supply, low-quality irrigation water, low soil fertility, high daytime temperatures with high evapotranspiration rates, or soil salinity (Abdel-Rahman et al., 2011; Al-Karaki, 2000). Among the numerous benefits offered by mycorrhizae are increased absorption of mineral elements, which enhances a plant's defense against pathogens and drought conditions (Jeffries et al., 2003).

Therefore, the objective of this study was to evaluate the individual and combined effects of the Ca:Mg ratio, MF exposure, and amendment with mycorrhizae on the yield and mineral composition of rose geranium.

Materials and Methods

The experimental trial was carried out in a 40 m × 15 m greenhouse at the Glen College of Agriculture, located in the Mangaung

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Municipality in the Free State Province of the Republic of South Africa. The geographical position of the college is lat. 28°55'S and long. 26°19'E and an altitude of 1307 m above sea level. The study was conducted during the 2015/2016 growing season and was repeated during the 2017/2018 growing season. Transplanting took place in September, and harvesting was carried out in April for both seasons.

Rose geranium cuttings (± 12 cm) were transplanted in 5-L potting bags filled with sterile silica sand during the 2015/2016 and 2016/2017 growing seasons. A 230-V, 18-W Wortex fountain FP 15 water pump with a flow rate of 900 L/h was used to fertigate experimental plants. The recirculating system had four dripper tubes allocated to four pots consisting of a single plant. The plants were irrigated twice a day for the first month, at 1130 and 1400 HR, in a closed recirculating irrigation system. The irrigation volume was gradually increased to three times a day, at 0800, 1200, and 1600 HR, to ensure that 10% to 15% of the water was leached out to reduce any build-up of salt in the root medium. The nutrient solution was replaced with fresh solution at 3-week intervals during the experimental periods.

Nutrient solutions were prepared to provide three levels of Ca:Mg ratios (Table 1). Other micro elements were supplied in amounts of 6.54 g Fe, 1.89 g B, 0.13 g Mo, 1.16 g Zn, and 2.11 g Mn per 1000 L of water. A pH level of 5.5 was maintained by adding 79 mL of HNO₃ (60%) per 1000 L of water. The electrical conductivity was 1.55 mS·cm⁻¹. The mycorrhizal strains used in this study were Mycoroot™ SuperGo products [Mycoroot™ (Pty.) Ltd., Grahamstown, South Africa]. They consisted of five different species of arbuscular mycorrhizal isolates: *Rhizophagus clarus*, *Gigaspora gigantea*, *Funneliformis mosseae*, *Claroideoglomus etunicatum*, and *Paraglomus occulum*. Two north-facing magnets each weighing 56.4 g and each with a length and width of 4.5 and 2.0 cm, respectively (110.1 mT) were placed at the bottoms of 5-L potting bags used in the MF treatments.

Layout. Treatments were arranged in a completely randomized block design with three replications, using a 3 × 2 factorial design, with the mycorrhizal treatment applied in a split. Three levels of the Ca:Mg ratio (2.40:6.78, 4.31:4.39, and 6.78:2.40 meq·L⁻¹), 6.78 Ca:2.40 Mg meq·L⁻¹ denoted by “High-Ca:Low-Mg,” equal proportion of Ca and Mg (4.31 Ca:4.39 Mg meq·L⁻¹) represented by EP-Ca:Mg, and 2.32 Ca:6.38 Mg meq·L⁻¹ denoted by “Low-Ca:High-Mg,” two levels of MF (no MF, denoted by “0 MF,” and 110 mT, denoted by “1 MF”) and split treatments of mycorrhizae (zero mycorrhizae denoted by “0 Myco,” and 20 mL mycorrhizae denoted by “1 Myco”) were used in this study.

Agronomic attribute measurements. Plant height, number of branches, number of leaves, root length, chlorophyll, leaf dry mass, branch dry mass, and root dry mass were measured at harvesting (6 months after

transplanting). Foliar material was oven dried at 60 °C for 96 h. The dried samples were milled (0.30-mm diameter), using a method described by Sedibe and Allemann (2013). The chlorophyll content was determined randomly from the upper six mature leaves on the crop using a portable nondestructive chlorophyll meter (CCM-200; Opti-Sciences, Hudson, NH), following a procedure described by Chen and Black (1992). The chlorophyll content was determined at harvesting.

Mineral analyses. Mineral contents (N, P, K, Ca, Mg, S, Fe, Zn, Cu, and B) were measured separately for both leaf and stem samples using a Dumas combustion method (Etheridge et al., 1998; Matejović, 1996) with a Leco FP-528 combustion nitrogen analyzer (LecoCorp, St. Joseph, MI).

Statistical analyses. The data collected were analyzed using the SAS statistical analysis software (SAS Institute, Cary, NC). Tukey's Student range test was used to separate means that were significantly different at $P < 0.05$, as described by Steel and Torrie (1980).

Results

Agronomic attributes

Agronomic attribute data are shown in Table 2. Ca:Mg ratio had a significant effect on the number of leaves per plant, leaf, stem and the dry mass of the root. It can be seen from Table 2 that plants treated with equal proportions of Ca and Mg in the nutrient solution grew taller ($P < 0.05$) and had the highest number of leaves ($P < 0.05$), resulting in an increased dry mass of leaves ($P < 0.01$) and branches ($P < 0.05$). The interaction between the Ca:Mg ratio and exposure to an MF field had a significant ($P < 0.05$) effect on the number of leaves produced by rose geranium. A smaller number of leaves (19/plant) were obtained when rose geranium plants were exposed to 1 MF using a nutrient solution containing Low-Ca:High-Mg than when nutrient solutions with EP-Ca:Mg and with High-Ca:Low-Mg 1 MF were used. A significant ($P < 0.05$) interaction effect between the Ca:Mg ratio and MF was observed on plant height. Plants that were grown using a nutrient solution containing Low-Ca:High-Mg 1 MF and High-Ca:Low-Mg 0 MF were relatively shorter than plants grown using EP-Ca:Mg nutrient solution. Exposure of rose geranium plants to a MF of 110 mT affected plant height significantly, with an increase in the number of branches and a longer root system. The interaction between Ca:Mg ratio and 1 Myco had a significant

($P < 0.05$) effect on the chlorophyll content. Plants grown using EP-Ca:Mg 1 Myco had a better leaf chlorophyll concentration.

Stem and leaf mineral composition

Stem and leaf mineral composition results are shown in Table 3.

Stem mineral composition

Nitrogen. The interaction between Ca:Mg ratio, MF, and mycorrhizae had a significant ($P < 0.05$) effect on N accumulation in the stem. Table 3 shows that a relatively high N content accumulated in rose geranium stems that were fertigated with a nutrient solution with approximately equal proportions of Ca and Mg, in conjunction with 1 MF exposure where no mycorrhizae was applied (Fig. 1) compared with plants treated with High-Ca:Low-Mg with or without MF or Myco, but not significantly different from plants grown a relatively Low-Ca:High-Mg 1 MF 1 Myco treatment.

Ca, K, and Mg. The ratio of Ca to Mg had a significant effect on the K ($P < 0.01$), Ca ($P < 0.05$), and Mg ($P < 0.05$) concentrations in the stem. As Table 3 shows, mineral accumulation in the stem was significantly affected when 2.40 Ca meq·L⁻¹ was used with 6.78 Mg meq·L⁻¹. Calcium concentrations in the stem increased with High-Ca:Low-Mg ratio, but Mg concentrations decreased concurrently. Potassium concentration in the stem decreased when Ca and Mg were applied in equal proportions.

Zinc. MF had a significant effect on Zn ($P < 0.05$) concentration in the stem, by which Zn accumulation was decreased by MF exposure. The interaction between the Ca:Mg ratio and mycorrhizae amendment had a significant ($P < 0.05$) effect on Zn accumulation in the stem. Application of EP-Ca:Mg in the nutrient solution amended with mycorrhizae increased Zn accumulation in the stem in comparison with all other treatments considered in this study (Table 3).

Copper. The interaction between the Ca:Mg ratio, MF, and mycorrhizal amendment had a significant ($P < 0.01$) effect on Cu accumulation in the stem. Table 3 shows that a High-Ca:Low-Mg ratio together with 0 MF and 20 mL of mycorrhizae per plant, as well as with 1 MF, increased the level of Cu in the same way as an EP-Ca:Mg ratio of 4.31:4.39 meq·L⁻¹ without MF but with mycorrhizal amendment (Table 3).

Leaf mineral composition

Magnesium. The ratio of Ca to Mg had a significant ($P < 0.01$) effect on the concentration

Table 1. Cations of nutrient solutions used to study effects of Ca:Mg ratio, magnetic field, and mycorrhizal fungi on yield and mineral composition of rose geranium.

Ratio	Ion ratios (meq·L ⁻¹)									
	Na ⁺	NH ₄ ⁺	K ⁺	Ca ²⁺	Mg ²⁺	NO ₃ ⁻	H ₂ PO ₄ ⁻	SO ₄ ²⁻	Cl ⁻	HCO ₃ ⁻
High-Ca:Low-Mg	0.54	1.00	5.30	6.30	2.40	10.18	1.60	3.20	0.28	0.40
EP-Ca:Mg	0.54	1.00	5.30	4.31	4.39	10.18	1.60	3.20	0.28	0.40
Low-Ca:High-Mg	0.54	1.00	5.30	2.32	6.38	10.18	1.60	3.20	0.28	0.40

High-Ca:Low-Mg = 6.78 Ca:2.40 Mg meq·L⁻¹, EP-Ca:Mg = equal proportion of Ca and Mg = 4.31 Ca:4.39 Mg meq·L⁻¹, Low-Ca:High-Mg = 2.32 Ca: 6.38 Mg meq·L⁻¹.

Table 2. Effect of Ca:Mg ratio, magnetic field, and mycorrhizae on agronomic attributes of rose geranium.

Treatments	Agronomic attributes						
	Plant ht (cm)	No. of branches/plant	No. of leaves/plant	Root length (cm)	Chlorophyll	Leaf dry mass/plant	Branch dry mass/plant
Ratio							
High-Ca:Low-Mg	25.3 ± 5.2 a	26.9 ± 7.6 a	26.9 ± 8.0 a	23.6 ± 5.7 a	30.8 ± 30.1 a	31.5 ± 11.0 a	11.9 ± 5.9 a
EP-Ca:Mg	28.5 ± 6.6 b	25.1 ± 3.9 a	27.8 ± 7.3 a	26.6 ± 4.8 a	35.9 ± 7.4 a	38.9 ± 12.1 a	13.5 ± 5.3 a
Low-Ca:High-Mg	25.3 ± 5.3 a	23.3 ± 3.9 a	21.6 ± 5.3 b	23.9 ± 5.0 a	32.0 ± 9.6 a	24.6 ± 9.3 b	7.7 ± 2.8 b
LSD _{0.05}	5.9*	5.2 ^{NS}	7.9*	3.2 ^{NS}	9.3 ^{NS}	11.2**	4.3*
MF							
0 MF	24.2 ± 5.3 a	22.5 ± 4.8 a	23.7 ± 5.7 a	22.7 ± 4.7 a	32.5 ± 8.7 a	30.1 ± 12.3 a	10.1 ± 4.1 a
1 MF	28.5 ± 5.6 b	27.7 ± 5.9 b	27.1 ± 8.4 a	26.7 ± 5.1 b	33.3 ± 6.7 a	33.3 ± 12.1 a	12.0 ± 5.7 a
LSD _{0.05}	4.8**	4.2**	6.4 ^{NS}	2.6*	7.6 ^{NS}	9.2 ^{NS}	3.5 ^{NS}
Myco							
0 Myco	27.1 ± 6.5 a	25.8 ± 6.4 a	26.5 ± 7.7 a	23.6 ± 4.7 a	31.8 ± 7.6 a	33.2 ± 11.9 a	11.8 ± 5.6 a
1 Myco	25.6 ± 5.1 a	24.4 ± 5.5 a	24.3 ± 7.1 a	25.8 ± 5.9 a	34.0 ± 7.8 a	30.2 ± 12.5 a	10.3 ± 4.3 a
LSD _{0.05}	2.4 ^{NS}	3.3 ^{NS}	3.9 ^{NS}	3.5 ^{NS}	3.6 ^{NS}	7.1 ^{NS}	3.4 ^{NS}
Ratio × MF							
High-Ca:Low-Mg 0 MF	21.5 ± 4.5 a	22.0 ± 5.5 a	22.3 ± 4.9 ab	19.2 ± 4.7 a	30.3 ± 3.7 a	27.3 ± 12.0 a	11.0 ± 6.0 a
High-Ca:Low-Mg 1 MF	29.0 ± 2.5 a	31.8 ± 6.3 a	31.5 ± 8.2 a	28.0 ± 1.9 a	31.3 ± 6.5 a	35.7 ± 9.0 a	12.8 ± 3.8 a
EP-Ca:Mg 0 MF	24.3 ± 5.3 a	22.7 ± 6.5 a	25.3 ± 8.0 ab	25.3 ± 3.6 a	34.5 ± 9.8 a	36.4 ± 12.3 a	11.4 ± 2.3 a
EP-Ca:Mg 1 MF	32.7 ± 5.2 a	27.5 ± 3.8 a	30.2 ± 6.2 ab	27.8 ± 5.9 a	37.3 ± 4.4 a	41.5 ± 12.3 a	15.7 ± 6.8 a
Low-Ca:High-Mg 0 MF	26.8 ± 5.6 a	22.8 ± 2.5 a	23.5 ± 4.4 ab	23.5 ± 3.9 a	32.9 ± 11.7 a	26.6 ± 11.9 a	8.0 ± 3.0 a
Low-Ca:High-Mg 1 MF	23.8 ± 5.0 b	23.8 ± 5.2 a	19.7 ± 5.9 b	24.3 ± 6.3 a	31.2 ± 7.9 a	22.6 ± 6.1 a	7.5 ± 3.0 a
LSD _{0.05}	8.4 ^{NS}	7.3 ^{NS}	11.1*	4.5 ^{NS}	2.2 ^{NS}	15.9 ^{NS}	6.1 ^{NS}
Ratio × Myco							
High-Ca:Low-Mg 0 Myco	26.0 ± 6.3 a	29.2 ± 8.5 a	28.3 ± 9.8 a	23.8 ± 4.8 a	29.7 ± 5.5 b	36.0 ± 8.8 a	13.9 ± 4.3 a
High-Ca:Low-Mg 1 Myco	24.5 ± 4.4 a	24.7 ± 6.6 a	25.5 ± 6.3 a	23.3 ± 7.0 a	31.9 ± 4.8 b	27.0 ± 11.9 a	9.9 ± 4.9 a
EP-Ca:Mg 0 Myco	28.7 ± 7.5 a	25.0 ± 4.6 a	29.3 ± 6.9 a	24.0 ± 3.4 a	31.6 ± 4.6 b	40.0 ± 11.8 a	14.1 ± 6.7 a
EP-Ca:Mg 1 Myco	28.3 ± 6.3 a	25.2 ± 7.1 a	26.2 ± 7.9 a	29.2 ± 4.8 a	40.3 ± 7.2 a	37.9 ± 13.5 a	12.9 ± 4.1 a
Low-Ca:High-Mg 0 Myco	26.7 ± 6.5 a	23.3 ± 5.1 a	22.0 ± 3.4 a	23.0 ± 6.4 a	34.2 ± 11.4 ab	23.5 ± 9.4 a	7.5 ± 3.1 a
Low-Ca:High-Mg 1 Myco	24.0 ± 3.9 a	23.3 ± 2.9 a	21.2 ± 7.1 a	24.8 ± 3.4 a	29.9 ± 7.7 b	25.7 ± 10.0 a	8.0 ± 2.8 a
LSD _{0.05}	2.2 ^{NS}	5.6 ^{NS}	6.7 ^{NS}	6.0 ^{NS}	6.1*	12.3 ^{NS}	6.0 ^{NS}
MF × Myco							
0 MF 0 Myco	24.4 ± 5.8 a	23.8 ± 3.6 a	24.2 ± 5.0 a	21.7 ± 3.0 a	30.1 ± 8.7 a	32.1 ± 11.5 a	11.3 ± 4.6 a
0 MF 1 Myco	24.0 ± 5.2 a	21.2 ± 5.7 a	23.2 ± 6.6 a	23.7 ± 5.9 a	35.0 ± 8.4 a	28.0 ± 13.4 a	8.9 ± 3.4 a
1 MF 0 Myco	29.8 ± 6.3 a	27.9 ± 8.1 a	28.9 ± 9.2 a	25.6 ± 5.5 a	33.6 ± 6.2 a	34.2 ± 12.9 a	12.4 ± 6.7 a
1 MF 1 Myco	27.2 ± 4.7 a	27.6 ± 3.1 a	25.3 ± 7.8 a	27.9 ± 4.6 a	33.0 ± 7.5 a	32.4 ± 11.8 a	11.7 ± 4.9 a
LSD _{0.05}	3.3 ^{NS}	4.7 ^{NS}	5.4 ^{NS}	4.9 ^{NS}	5.0 ^{NS}	2.2 ^{NS}	4.9 ^{NS}
Ratio × MF × Myco							
High-Ca:Low-Mg = 6.78 Ca:2.40 Mg meq.L ⁻¹ , EP-Ca:Mg = equal proportion of Ca and Mg = 4.31 Ca:4.39 Mg meq.L ⁻¹ , Low-Ca:High-Mg = 2.32 Ca:6.38 Mg meq.L ⁻¹ , 0 MF = zero magnetic field, 1 MF = 110.1-mT magnetic field, 0 Myco = zero mycorrhizae, 1 Myco = 20 mL mycorrhizae per plant, LSD = least significant difference.	5.8 ^{NS}	8.2 ^{NS}	9.4 ^{NS}	8.5 ^{NS}	8.7 ^{NS}	17.4 ^{NS}	8.4 ^{NS}
LSD _{0.05}							
High-Ca:Low-Mg = 6.78 Ca:2.40 Mg meq.L ⁻¹ , EP-Ca:Mg = equal proportion of Ca and Mg = 4.31 Ca:4.39 Mg meq.L ⁻¹ , Low-Ca:High-Mg = 2.32 Ca:6.38 Mg meq.L ⁻¹ , 0 MF = zero magnetic field, 1 MF = 110.1-mT magnetic field, 0 Myco = zero mycorrhizae, 1 Myco = 20 mL mycorrhizae per plant, LSD = least significant difference.							
NS, Not significant at $P < 0.05$, *significant at $P < 0.05$, **significant at $P < 0.01$, ***significant at $P < 0.0001$.							
Means followed by the same letter within a column do not differ significantly at $P < 0.05$.							

Table 3. Effects of Ca:Mg ratio, magnetic field, and mycorrhizae on stem and leaf mineral concentration of rose geranium.

Treatments	Stem mineral composition (mg kg ⁻¹ DW)									
	N (%)	P	K	Ca	Mg	S	Fe	Zn	B	Cu
Ratio										
High-Ca:Low-Mg	1.86 ± 0.5 a	4.131.1 ± 889.2 a	32.841 ± 7.007.7 a	12.615 ± 3.544.2 a	2.541.4 ± 370.4 b	1.786.7 ± 343.7 a	290.50 ± 190.0 a	98.33 ± 25.5 a	29.33 ± 11.4 a	7.63 ± 2.6 a
EP-Ca:Mg	1.72 ± 0.6 a	3.652.0 ± 880.1 a	29.636 ± 5.894.7 b	10.302 ± 2.470.1 b	3.219.4 ± 722.2 a	1.766.0 ± 367.6 a	330.00 ± 157.5 a	96.73 ± 29.4 a	30.39 ± 16.6 a	6.80 ± 2.1 ab
Low-Ca:High-Mg	1.73 ± 0.4 a	4.041.2 ± 944.5 a	36.238 ± 3.403.6 a	8.732 ± 773.7 b	3.756.2 ± 593.9 a	1.811.3 ± 329.2 a	209.67 ± 242.7 a	87.58 ± 16.3 a	24.78 ± 10.9 a	5.82 ± 1.0 b
LSD _{0.05}	0.52 ^{NS}	950.1 ^{NS}	4,360.7 ^{**}	2,265.6 [*]	616.37 ^{**}	345.1 ^{NS}	156.88 ^{NS}	21.76 ^{NS}	10.33 ^{NS}	1.46 [*]
MF										
0 MF	1.66 ± 0.3 a	3.921.2 ± 751.0 a	33.579 ± 6.000.6 a	10.583.6 ± 2.568.6 a	3.109.4 ± 720.2 a	1.801.6 ± 274.9 a	222.50 ± 143.9 a	100.717 ± 24.1 a	24.97 ± 4.7 a	6.99 ± 2.4 a
1 MF	1.89 ± 0.6 a	3.961.6 ± 1,056.7 a	32.231 ± 6.338.4 a	10.516.2 ± 3,353.9 a	3.235.2 ± 806.6 a	1,774.4 ± 398.5 a	330.94 ± 236.5 a	87.706 ± 23.0 b	31.36 ± 17.5 a	6.51 ± 1.7 a
LSD _{0.05}	0.42 ^{NS}	775.78 ^{NS}	3,560.5 ^{NS}	1,849.9 ^{NS}	503.26 ^{NS}	281.78 ^{NS}	128.09 ^{NS}	17.77 ^{**}	844 ^{NS}	1.19 ^{NS}
Myc										
0 Myco	1.72 ± 0.5 a	3.840.4 ± 856.1 a	32.629 ± 6.442.9 a	10.839.1 ± 3,465.3 a	3.102.6 ± 738.6 a	1.780.4 ± 278.5 a	278.67 ± 213.9 a	90.82 ± 19.6 a	30.26 ± 13.3 a	6.46 ± 1.9 a
1 Myco	1.82 ± 0.4 a	4.042 ± 4,962.9 a	33.181 ± 5,955.9 a	10.260.6 ± 2,379.8 a	3,242.1 ± 788.6 a	1,795.6 ± 396.3 a	274.78 ± 192.6 a	97.60 ± 28.2 a	26.07 ± 12.9 a	7.04 ± 2.3 a
LSD _{0.05}	0.25 ^{NS}	552.5 ^{NS}	4,848 ^{NS}	1,685.7 ^{NS}	399.55 ^{NS}	267.9 ^{NS}	133.9 ^{NS}	11.7 ^{NS}	10.2 ^{NS}	0.8 ^{NS}
Ratio × MF										
High-Ca:Low-Mg 0 MF	1.75 ± 0.4 a	4.079.3 ± 537.8 a	35.234 ± 4,911.8 a	11.828 ± 2,125.0 a	2,635.8 ± 434.8 a	1,852.0 ± 246.0 a	298.83 ± 218.2 a	104.03 ± 22.5 ab	27.53 ± 4.6 a	7.70 ± 3.2 a
High-Ca:Low-Mg 1 MF	1.98 ± 0.6 a	4.182.8 ± 1,201.5 a	30.448 ± 8,376.2 a	13.402 ± 4,651.2 a	2,447.0 ± 302.3 a	1,721.3 ± 435.0 a	282.17 ± 177.9 a	92.62 ± 29.2 ab	31.12 ± 16.1 a	7.57 ± 2.2 a
EP-Ca:Mg 0 MF	1.55 ± 0.2 a	3.541.5 ± 472.3 a	28.323 ± 5,949.3 a	11.370 ± 3,114.2 a	3,029.7 ± 760.4 a	1,753.7 ± 361.5 a	226.50 ± 86.3 a	112.60 ± 29.3 a	24.48 ± 4.0 a	7.47 ± 2.6 a
EP-Ca:Mg 1 MF	1.89 ± 0.8 a	3.762.5 ± 1,204.8 a	30.948 ± 6,075.8 a	9.235 ± 995.7 a	3,409.2 ± 695.0 a	1,778.3 ± 407.7 a	433.50 ± 310.6 a	80.85 ± 21.0 b	36.30 ± 22.5 a	6.13 ± 1.5 a
Low-Ca:High-Mg 0 MF	1.67 ± 0.1 a	4.142.8 ± 1,069.2 a	37.180 ± 3,303.3 a	8.553 ± 818.1 a	3,662.8 ± 593.2 a	1,799.0 ± 245.0 a	142.17 ± 23.6 a	85.52 ± 12.5 ab	22.90 ± 5.0 a	5.82 ± 1.0 a
Low-Ca:High-Mg 1 MF	1.80 ± 0.5 a	3.939.5 ± 891.4 a	35.297 ± 3,528.3 a	8.912 ± 755.3 a	3,849.5 ± 635.0 a	1,823.5 ± 422.1 a	277.17 ± 207.5 a	89.65 ± 20.5 ab	26.67 ± 15.05 a	5.82 ± 1.2 a
LSD _{0.05}	0.7 ^{NS}	1343 ^{NS}	6,167 ^{NS}	3,204 ^{NS}	871.7 ^{NS}	488.1 ^{NS}	221.9 ^{NS}	30.78 ^{**}	14.61 ^{NS}	2.06 ^{NS}
Ratio × Myco										
High-Ca:Low-Mg 0 Myco	1.71 ± 0.5 a	3.951.0 ± 1,052.7 a	30.841 ± 9,119.4 a	13.869 ± 4,368.7 a	2,471.0 ± 192.9 a	1,733.2 ± 256.2 a	248.5 ± 87.9 a	99.28 ± 20.8 ab	28.25 ± 4.3 a	7.67 ± 2.3 a
High-Ca:Low-Mg 1 Myco	2.02 ± 0.0 a	4.311.2 ± 743.9 a	34.841 ± 3,907.8 a	11.361 ± 2,185.5 a	2,611 ± 502.7 a	1,840.2 ± 33.0 a	332.3 ± 259.8 a	97.37 ± 31.6 ab	30.40 ± 16.3 a	7.60 ± 3.1 ab
EP-Ca:Mg 0 Myco	1.88 ± 0.7 a	3.454 ± 289.1 a	30.165 ± 3,563.3 a	10.126 ± 1,728.9 a	3,192.3 ± 781.2 a	1,801.2 ± 377.4 a	440.8 ± 305.9 a	82.20 ± 22.1 a	38.28 ± 21.0 a	6.25 ± 1.7 b cd
EP-Ca:Mg 1 Myco	1.56 ± 0.3 a	3.849.3 ± 1,235.5 a	29.107 ± 7,958.4 a	10.479 ± 3,218.6 a	3,246.5 ± 731.8 a	1,730.8 ± 389.7 a	219.2 ± 80.8 a	111.25 ± 30.2 a	22.50 ± 4.0 a	7.35 ± 2.5 abc
Low-Ca:High-Mg 0 Myco	1.56 ± 0.3 a	4.115.70 ± 1,007.9 a	36.882 ± 3,564.9 a	8.522 ± 829.0 a	3,644 ± 605.6 a	1,806.8 ± 271.2 a	146.7 ± 24.9 a	90.98 ± 14.4 ab	24.25 ± 3.9 a	5.45 ± 1.2 d
Low-Ca:High-Mg 1 Myco	1.90 ± 0.5 a	3.966.7 ± 966.2 a	35.594 ± 3,432.6 a	8.942 ± 723.8 a	3,868.0 ± 615.8 a	1,815.7 ± 432.2 a	272.7 ± 210.7 a	84.18 ± 18.7 b	25.31 ± 15.6 a	6.18 ± 0.7 cd
LSD _{0.05}	0.44 ^{NS}	957 ^{NS}	8,398 ^{NS}	2,919.8 ^{NS}	692.04 ^{NS}	464 ^{NS}	232.1 ^{NS}	20.34 [*]	17.6 ^{NS}	1.4 [*]
MF × Myco										
0 MF 0 Myco	1.56 ± 0.2 a	3.796.3 ± 734.7 a	32.950 ± 5,996.3 a	10.504 ± 2,053.5 a	2,911.2 ± 691.3 a	1,761.1 ± 281.4 a	215.11 ± 83.9 a	89.33 ± 12.2 b	27.08 ± 3.3 a	5.70 ± 1.4 b
0 MF 1 Myco	1.75 ± 0.2 a	4.046.1 ± 789.6 a	34.209 ± 6,298.2 a	10.663 ± 3,128.8 a	3,307.7 ± 732.0 a	1,842.0 ± 278.7 a	229.89 ± 83.9 a	112.10 ± 28.2 a	22.785.1 ± a	8.98 ± 2.7 a
1 MF 0 Myco	1.90 ± 0.6 a	3.884.6 ± 1,006.5 a	32.309 ± 7,212.9 a	11.174 ± 4,587.9 a	3,293.9 ± 774.0 a	1,799.7 ± 291.1 a	342.22 ± 284.7 a	92.31 ± 25.7 b	33.44 ± 18.4 a	7.21 ± 2.2 a
1 MF 1 Myco	1.89 ± 0.7 a	4.038.7 ± 1,160 a	32.153 ± 5,773.6 a	9.858 ± 1,371.8 a	3,176.6 ± 880.8 a	1,749.1 ± 501.2 a	319.67 ± 193.6 a	83.10 ± 20.5 b	29.28 ± 17.4 a	5.80 ± 0.8 b
LSD _{0.05}	0.36 ^{NS}	781.3 ^{NS}	6,857 ^{NS}	2,384 ^{NS}	565 ^{NS}	379 ^{NS}	189.5 ^{NS}	16.6 [*]	14.4 ^{NS}	1.13 [*]
Ratio × MF × Myco										
LSD _{0.05}	0.62 [*]	1,352 ^{NS}	18,877 ^{NS}	4,129 ^{NS}	979 ^{NS}	656 ^{NS}	328 ^{NS}	29 ^{NS}	25 ^{NS}	1.96 ^{**}
Ratio										
High-Ca:Low-Mg	2.54 ± 0.5 a	4.469.8 ± 821.9 a	29.335 ± 3,182.4 a	11.247.7 ± 1,503.1 a	3,282.7 ± 851.4 b	2,239.1 ± 353.3 a	1,102.7 ± 1,197.1 a	66.1 ± 32.5 ab	64.6 ± 19.8 a	8.91 ± 6.7 a
EP-Ca:Mg	2.51 ± 0.5 a	4.302.8 ± 1,204.3 a	27.529 ± 7,693.6 a	10.579.2 ± 798.9 a	3,682.7 ± 342.2 ab	2,226.8 ± 387.0 a	1,632.0 ± 1,827.0 a	77.3 ± 12.3 a	56.1 ± 12.6 a	11.15 ± 8.7 a
Low-Ca:High-Mg	2.79 ± 0.5 a	4,101.7 ± 607.3 a	32.472 ± 3,710.4 a	9,951.2 ± 1,582.9 a	4,138.4 ± 786.1 a	2,315.2 ± 175.5 a	1,081.2 ± 685.0 a	52.4 ± 30.7 b	61.9 ± 19.6 a	7.64 ± 4.2 a
LSD _{0.05}	0.42 ^{NS}	922.42 ^{NS}	5,879.1 ^{NS}	1,193.3 ^{NS}	470.66 ^{**}	296.3 ^{NS}	853.1 ^{NS}	19.2 [*]	17.8 ^{NS}	3.65 ^{NS}
MF										
0 MF	2.63 ± 0.4 a	4.213.7 ± 822.3 a	29.631 ± 6,102.4 a	10.621.2 ± 1,451.3 a	3,763.9 ± 674.1 a	2,297.7 ± 335.1 a	1,474.1 ± 1,506.6 a	67.49 ± 30.0 a	61.77 ± 14.9 a	10.54 ± 7.9 a
1 MF	2.59 ± 0.5 a	4,369.2 ± 986.5 a	29.926 ± 5,030.9 a	10,564.1 ± 1,407.7 a	3,638.6 ± 860.7 a	2,222.9 ± 292.6 a	1,069.8 ± 1,082.5 a	63.02 ± 26.4 a	60.06 ± 20.3 a	7.92 ± 5.3 a
LSD _{0.05}	0.34 ^{NS}	753.16 ^{NS}	4,800.3 ^{NS}	974.3 ^{NS}	384.3 ^{NS}	241.9 ^{NS}	696.5 ^{NS}	15.69 ^{NS}	14.6 ^{NS}	2.98 ^{NS}

(Continued on next page)

Table 3. (Continued) Effects of Ca:Mg ratio, magnetic field, and mycorrhizae on stem and leaf mineral concentration of rose geranium.

Treatments	N (%)	P	K	Ca	Mg	S	Leaf mineral composition (mg kg ⁻¹ DW)			
							Fe	Zn	B	Cu
Mycor										
0 Myco	2.53 ± 0.4 a	4,156.8 ± 980.6 a	29,151 ± 6,602.9 a	10,576.3 ± 1,608.4 a	3,782.7 ± 807.1 a	2,248.78 ± 317.7 a	1,270.1 ± 1,332.7 a	69.80 ± 35.3 a	59.58 ± 18.3 a	9,350 ± 7.4 a
1 Myco	2.70 ± 0.4 a	4,426.1 ± 813.7 a	30,407 ± 4,261.5 a	10,609.0 ± 1,225.6 a	3,619.8 ± 733.5 a	2,271.89 ± 315.6 a	1,273.8 ± 1,323.6 a	60.71 ± 17.8 a	62.23 ± 17.1 a	9,12 ± 6.2 a
LSD _{0.05}	0.34 ^{NS}	688.7 ^{NS}	3,592.7 ^{NS}	982.93 ^{NS}	428.71 ^{NS}	206.06 ^{NS}	766.9 ^{NS}	13.54 ^{NS}	12.98 ^{NS}	3.25 ^{NS}
Ratio × MF										
High-Ca:Low-Mg 0 MF	2.52 ± 0.5 a	4,722.3 ± 408.9 a	30,079 ± 3,426.1 a	11,752.2 ± 1,471.6 a	3,524.8 ± 744.5 a	2,329.7 ± 279.2 a	1,062.8 ± 1,200.6 a	74.12 ± 44.7 a	63.28 ± 19.5 a	9,48 ± 7.6 a
High-Ca:Low-Mg 1 MF	2.57 ± 0.7 a	4,217.3 ± 1,079.6 a	28,590 ± 3,035.2 a	10,743.2 ± 1,481.3 a	3,040.5 ± 948.5 a	2,148.5 ± 420.7 a	1,142.5 ± 1,306.6 a	58.07 ± 13.1 a	66.10 ± 21.9 a	8,33 ± 6.5 a
EP-Ca:Mg 0 MF	2.56 ± 0.3 a	3,847.8 ± 1,181.1 a	24,923 ± 6,904.6 a	10,115.3 ± 1,385.0 a	3,761.2 ± 321.3 a	2,217.8 ± 513.8 a	2,281.3 ± 2,108.1 a	73.87 ± 23.8 a	60.37 ± 13.9 a	14,28 ± 10.3 a
EP-Ca:Mg 1 MF	2.46 ± 0.6 a	4,757.8 ± 1,139.6 a	30,136 ± 8,139.1 a	11,043.0 ± 1,754.3 a	3,604.2 ± 373.6 a	2,235.7 ± 255.6 a	982.7 ± 1,373.8 a	80.65 ± 38.4 a	51.83 ± 24.7 a	8,02 ± 6.1 a
Low-Ca:High-Mg 0 MF	2.83 ± 0.2 a	4,071.0 ± 491.2 a	33,892 ± 4,309.9 a	9,906.2 ± 875.4 a	4,005.8 ± 865.2 a	2,345.7 ± 167.9 a	1,078.0 ± 811.4 a	54.50 ± 13.9 a	61.65 ± 13.2 a	7,87 ± 4.9 a
Low-Ca:High-Mg 1 MF	2.75 ± 0.2 a	4,132.3 ± 753.5 a	31,053 ± 2,622.3 a	9,906.2 ± 795.5 a	4,271.0 ± 754.1 a	2,284.7 ± 193.1 a	1,084.3 ± 611.4 a	50.33 ± 11.4 a	62.23 ± 13.2 a	7,42 ± 3.9 a
LSD _{0.05}	0.59 ^{NS}	1,304.5 ^{NS}	8,314.3 ^{NS}	1,687.6 ^{NS}	665.62 ^{NS}	418.96 ^{NS}	1,206.4 ^{NS}	27.17 ^{NS}	25.24 ^{NS}	5.17 ^{NS}
Ratio × Myco										
High-Ca:Low-Mg 0 Myco	2.61 ± 0.4 a	4,446.2 ± 883.1 a	28,888 ± 3,609.5 a	11,199.7 ± 2,001.9 a	3,675.8 ± 926.6 a	2,336.8 ± 272.6 a	1,672.2 ± 1,524.9 a	71.92 ± 45.2 a	69.12 ± 12.3 a	11,33 ± 9.1 a
High-Ca:Low-Mg 1 Myco	2.47 ± 0.7 a	4,493.5 ± 839.7 a	2,978 ± 2,962.2 a	11,295.7 ± 978.6 a	2,889.5 ± 604.2 b	2,141.3 ± 421.0 a	539.2 ± 255.3 a	60.27 ± 14.2 a	60.27 ± 25.8 a	6,48 ± 1.8 a
EP-Ca:Mg 0 Myco	2.29 ± 0.6 a	4,076.8 ± 1,472.4 a	27,510 ± 10,781.2 a	10,382.5 ± 1,779.5 a	3,633.8 ± 409.9 a	2,138.8 ± 453.4 a	1,122.7 ± 1,747.7 a	86.57 ± 36.3 a	47.60 ± 22.6 a	9,983 ± 9.2 a
EP-Ca:Mg 1 Myco	2.73 ± 0.2 a	4,528.8 ± 948.7 a	27,549 ± 3,739 a	10,775.8 ± 1,500.9 a	3,731.5 ± 289.5 a	2,314.7 ± 324.7 a	214.3 ± 1,914.8 a	67.95 ± 23 a	64.60 ± 12.8 a	12,32 ± 8.9 a
Low-Ca:High-Mg 0 Myco	2.68 ± 0.2 a	3,947.3 ± 400.9 a	31,053 ± 3,363.8 a	10,146.8 ± 942.8 a	4,038.5 ± 1,034.1 a	2,270.7 ± 197.1 a	1,021.5 ± 608.8 a	53.92 ± 10.8 a	62.03 ± 13.7 a	6,73 ± 2.7 a
Low-Ca:High-Mg 1 Myco	2.89 ± 0.1 a	4,256.0 ± 770.4 a	33,892 ± 3,760.0 a	9,755.5 ± 650.5 a	4,238.3 ± 515.8 a	2,359.7 ± 155.3 a	1,140.8 ± 808.1 a	50.92 ± 14.5 a	61.85 ± 12.7 a	8,55 ± 5.4 a
LSD _{0.05}	0.59 ^{NS}	1,192.8 ^{NS}	6,222.7 ^{NS}	1,702.5 ^{NS}	742.55 ^{NS}	356.91 ^{NS}	1,328.4 ^{NS}	23.44 ^{NS}	22.48 ^{NS}	5.62 ^{NS}
MF × Myco										
0 MF 0 Myco	2.54 ± 0.4 a	4,050.9 ± 803.2 a	27,879 ± 6,279.2 a	10,661.4 ± 1,856.4 a	3,726.6 ± 692.5 a	2,267.6 ± 396.9 a	1,441.2 ± 1,523.2 a	69.61 ± 38.7 a	64.80 ± 17.4 a	10,789 ± 9.1 a
0 MF 1 Myco	2.73 ± 0.3 a	4,376.6 ± 855.6 a	31,383 ± 5,727.0 a	10,581.0 ± 1,012.9 a	3,801.3 ± 694.9 a	2,327.9 ± 281.2 a	1,506.9 ± 1,581.3 a	65.38 ± 20.1 a	58.73 ± 12.2 a	10,30 ± 7.1 a
1 MF 0 Myco	2.51 ± 0.5 a	4,262.7 ± 1,171.7 a	30,422 ± 7,041.5 a	10,491.2 ± 1,426.5 a	3,838.9 ± 947.4 a	2,230.0 ± 237.1 a	1,099.0 ± 1,178.2 a	69.99 ± 34.0 a	54.37 ± 18.7 a	7,91 ± 5.5 a
1 MF 1 Myco	2.67 ± 0.5 a	4,475.7 ± 818.3 a	29,431 ± 1,909.9 a	10,637.0 ± 1,471.1 a	3,438.2 ± 765.6 a	2,215.9 ± 354.4 a	1,040.7 ± 1,048.6 a	56.04 ± 14.8 a	65.74 ± 21.2 a	7,93 ± 5.4 a
LSD _{0.05}	0.49 ^{NS}	973.9 ^{NS}	5,080.8 ^{NS}	1,309.1 ^{NS}	609.29 ^{NS}	291.41 ^{NS}	1,084.6 ^{NS}	19.14 ^{NS}	18.36 ^{NS}	4.59 ^{NS}
Ratio × MF × Myco										
LSD _{0.05}	0.84 ^{NS}	1,686.9 ^{NS}	8,800 ^{NS}	2,407 ^{NS}	1,050 ^{NS}	504.74 ^{NS}	1,878.6 ^{NS}	33.15 ^{NS}	31.80 ^{NS}	7.95 ^{NS}

DW = dry weight, High-Ca:Low-Mg = 6.78 Ca:2.40 Mg meq L⁻¹, EP-Ca:Mg = equal proportion of Ca and Mg = 4.31 Ca:4.39 Mg meq L⁻¹, Low-Ca:High-Mg = 2.32 Ca:6.38 Mg meq L⁻¹, 0 MF = zero magnetic field, 1 MF = 110.1-mT magnetic field, 0 Myco = zero mycorrhizae, 1 Myco = 20 mL mycorrhizae per plant, LSD = least significant difference.

NS, not significant at the $P < 0.05$, *significant at the $P < 0.05$, **significant at the $P < 0.01$, ***significant at the $P < 0.0001$. Means followed by the same letter within a column do not differ significantly at $P < 0.05$.

of Mg in the leaves of rose geranium (Table 3). Ca and Mg applied at a ratio of 2.40:6.78 meq L⁻¹ resulted in a greater concentration of Mg in the leaves but not a significantly different Mg concentration was obtained when equal proportion of Ca:Mg was used in the nutrient solution. It is evident that the concentration of Mg in the leaves decreased significantly with a Low-Mg:High-Ca ratio in the nutrient solution, whereas a High-Mg:Low-Ca ratio and EP-Ca and Mg in the nutrient solution resulted in significant increases in the Mg concentration in the leaves.

Zinc. Although there was no significant effect of the Ca:Mg ratio on the leaf B, Fe, or Cu contents, a significant effect of the Ca:Mg ratio on the leaf Zn content was detected ($P < 0.05$). Equal proportions of Ca and Mg in the nutrient solution significantly increased Zn concentration in the leaves in comparison with the two ratios considered in this study, Low-Ca:High-Mg and High-Ca:Low-Mg (Table 3).

Discussion

It was a hypothesis of this study that High-Ca:Low-Mg ratio, MF exposure, and amendment with mycorrhizae has a significant effect on growth and mineral composition of rose geranium. Application of Ca and Mg in approximately equal proportions of 4.31 and 4.39 meq L⁻¹ had significant effects on leaf Zn and stem Mg content. The application of Ca and Mg in equal proportions and in combination with either an MF or mycorrhizae had significant effects on plant height, chlorophyll content, stem-N, stem Cu, and stem Zn contents. Steiner's universal solution provided 9.00 and 4.00 meq L⁻¹ for Ca and Mg, respectively, contributing to 45% and 20% of the total cations (Combrink, 2013). Most of the nutrient solutions developed after Steiner's solution was developed have Ca:Mg ratios close to 3:1, even though these concentrations are adjusted to suit specific crop requirements (Combrink, 2013). In this study, the best growth was found with a Ca:Mg ratio close to 1:1. Because most greenhouse crops are grown with Ca:Mg ratios of ≈3:1, this may be an indication that rose geranium needs relatively high levels of Mg.

Various studies have shown a positive relationship between chlorophyll and the N content of plant leaves (Scheepers et al., 1992; Wang et al., 2004). The chlorophyll content is used as an alternative measure of the nitrogen status of most plant species (Fontes and de Araujo, 2006; Sedibe and Allemann, 2013). The accumulation of N observed in this study in the case of equal proportions of Ca and Mg, as well as with high Ca and low Mg in combination with no MF or mycorrhizae, could be attributable to the beneficial effect of mycorrhizae or an MF, which are said to improve root structure and N assimilation (Brady and Weil, 2002; Hozayn et al., 2016; Tisdale, et al., 1993). An MF affects the biochemical processes of plants that control free radicals. MF gradients activate phytohormones, such as gibberellic

Fig. 1. Effect of the interaction between Ca:Mg ratio, magnetic field, and mycorrhizae on stem-N concentration of rose geranium. High-Ca:Low-Mg = 6.78 Ca:2.40 Mg meq.L⁻¹, EP-Ca:Mg = equal proportion of Ca and Mg = 4.31 Ca:4.39 Mg meq.L⁻¹, Low-Ca:High-Mg = 2.32 Ca:6.38 Mg meq.L⁻¹, 0 MF = zero magnetic field, 1 MF = 110.1-mT magnetic field, 0 Myco = zero mycorrhizae, 1 Myco = 20 mL mycorrhizae per plant. Vertical lines on bars represent SE (n = 3).

acid, indole-3-acetic acid, and transzeatin, and also activate proteins and enzymes responsible for stem elongation and branching of plants (Hozayn and Qados, 2010; Maheshwari and Grewal, 2009). Increases in root length, root surface area, and root volume have been reported in chickpeas exposed to an MF of 250 mT (Vashisth and Nagarajan, 2008). Under the same conditions, sunflower seedlings have exhibited greater seedling dry mass, root length, root surface area, and root volume (Vashisth and Nagarajan, 2010).

The beneficial effects of applying Ca and Mg in approximately equal proportions were observed in this study regardless of whether it interacted with an MF or mycorrhizae. Furthermore, High-Ca and Low-Mg (6.78:2.40 meq.L⁻¹) in the nutrient solution significantly reduced the concentration of Mg in the leaves. Spiers and Braswell (2002) reported observing an increase in leaf Ca and a decrease in leaf Mg as a result of Ca application to blueberry plants. They also observed that increasing Mg fertilization resulted in increased leaf Mg content and decreased leaf Ca and leaf K (Spiers and Braswell, 2002). However, Shaul (2002) postulated that the Mg concentrations in different parts of a plant could be small, depending on the amount of Mg in the soil, the plant growth stage, and water stress. Kadir et al. (2004) found that a low application dose of Mg (<2%) reduced leaf concentration. However, no deficiency symptoms of Ca and Mg were observed when Mg and Ca were both added at lower doses (White, 2001).

On the other hand, a ratio of High-Ca to Low-Mg in the nutrient solution caused a small increase in the Zn concentration in comparison with that resulting from a ratio of High-Mg:Low-Ca ratio in the nutrient

solution. In contrast, Kawasaki and Moritugu (1987) reported that increased Ca in the nutrient solution significantly reduced Zn absorption and drastically inhibited the translocation of zinc. However, there was no significant relation between the Ca:Mg ratio with 0 MF and without mycorrhizae use.

Ca:Mg ratio, MF, and Myco did not significantly affect oil yield of rose geranium, although equal proportions of Mg and Ca with 1 MF and mycorrhizae use had a significant effect on the numbers of leaves per plant, leaf, stem, and the dry mass of the root (Table 3). However, summer savory oil content was increased by the application of calcium carbonate (Mumivand et al., 2011) and oil yield of oregano increased by 31% by the application of calcium and magnesium (Dordas, 2009).

Conclusion

The results of this study show that neither combinations of high Ca and low Mg nor low Ca and high Mg in the nutrient solution, together with mycorrhizae amendment, contribute to increased oil yield and mineral accumulation within rose geranium plants. However, agronomic attributes (plant height and chlorophyll content) and mineral composition (stem-N) were optimized when approximately equal proportions of Ca and Mg were applied in combination with exposure to an MF. This treatment can be useful in the production of rose geranium by enhancing the growth and mineral utilization of this crop.

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