Effects of Calcium and Magnesium on Plant Growth, Biomass Partitioning, and Fruit Yield of Winter Greenhouse Tomato

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Abstract. Tomato (*Lycopersicon esculentum* Mill) ‘Trust’ was grown on rockwool with nutrient solutions containing two levels of calcium (150 and 300 mg·L⁻¹) in factorial combination with three levels of magnesium (20, 50, and 80 mg·L⁻¹) in Winters 1997 and 1998, to investigate the effects of calcium and magnesium on growth, biomass partitioning, and fruit production. Plants grown at 20 mg·L⁻¹ Mg started to show Mg deficiency symptoms (leaf chlorosis) at 8 weeks after planting. The chlorophyll content of middle and bottom leaves increased with increasing Mg concentration in the nutrient solution. At 300 mg·L⁻¹ Ca, total fruit yield and fruit dry matter increased linearly with increasing Mg concentration; marketable fruit yield and total plant biomass showed similar response but to a lower degree. At 150 mg·L⁻¹ Ca, total plant biomass, fruit dry matter and yield peaked at 50 mg·L⁻¹ Mg. The biomass allocation to fruit increased while allocation to leaves decreased with increasing Mg concentration. The Mg effects on total and marketable fruit yield were mainly due to its influence on fruit yield in the late growth stage. Incidence of blossom-end rot (BER) at 150 mg·L⁻¹ Ca increased linearly with increasing Mg concentration while it was not affected by Mg concentration at 300 mg·L⁻¹ Ca. For a winter greenhouse tomato crop, the appropriate Ca and Mg concentrations for tomato production appear to be at 300 and 80 mg·L⁻¹, respectively.

Greenhouse tomato production and consumption in North America has increased substantially in the last few years. The share of greenhouse tomato in the fresh tomato market has increased from 1% in 1990 to 16% today (DeGiglio, 2003). In North America, almost all the greenhouse tomatoes are produced with a soilless culture system, mostly on rockwool. Rockwool releases little or no mineral nutrients and has a very low buffering capacity. Precise management of plant nutrition has a much larger influence on greenhouse tomato production in rockwool than on soil-based tomato production systems.

Effects of calcium (Ca) nutrition on growth, fruit yield and quality of greenhouse tomato have been investigated extensively in northern Europe (Ho et al., 1999). Leaf Ca deficiency in tomato reduces leaf size, and causes necrosis of young leaves and yield loss in extreme cases (Adams and Gizaway, 1988; Adams and Holder, 1992; Holder and Cockshull, 1990). Low supply of calcium to tomato fruit leads to more fruit with blossom-end rot (BER) (Ho et al., 1999; Saure, 2001). Excessive supply of calcium to fruit causes goldspeck/goldspot, cells containing a granular mass of tiny calcium oxalate crystals (De Kreij et al., 1992; Den Outer and van Veenendaal, 1988; Ho et

al., 1999), which not only affects the appearance of the fruit, but also reduces its shelf life (Janse, 1988).

Magnesium (Mg) deficiency occurs regularly in greenhouse tomatoes (Ontario Ministry of Agriculture and Food, 2001). Because the deficiency symptoms, usually in the main spring crop, occur on the oldest (bottom) less productive leaves, this has not been seen as a major problem. However, in fall or winter tomato crops, the deficiency may occur in the middle leaves, which could have significant influence on plant productivity (Sonneveld and Voogt, 1991). This reduction in plant productivity could be due to reduced biomass production (from low leaf photosynthesis) alone, or due to both a reduced overall biomass production and a lower biomass allocation to fruit. Information on the effects of mineral nutrients on biomass partitioning is useful for clarifying the mechanisms of their influence on fruit yield and is valuable for developing tomato growth models (Marcelis et al., 1998). There has been limited or no information available on the effects of Ca and Mg concentrations in the nutrient solution on biomass partitioning in greenhouse tomatoes.

Most of the information on Ca and Mg nutrition of greenhouse tomatoes is derived from research conducted in northern Europe; little such research has been done in North America. Past research (Adams, 1994; Ho et al., 1999; Papadopoulos and Hao, 2002; Sonneveld, 1987; Sonneveld and Voogt, 1991) has shown that the optimum levels of Ca and Mg for greenhouse tomatoes are strongly affected by climatic conditions such as solar irradiance,

humidity and temperature. Leamington (41 °N, continental climatic type) in Ontario, Canada, where one-third of North America greenhouse tomatoes are grown, has quite different climatic conditions from northern Europe (close to 50 °N, maritime climatic type). Therefore, there is a need to conduct experiments in this area for optimizing Ca and Mg nutrition. Furthermore, in a previous study designed to develop closed cultivation systems in Ontario, it appeared that high levels of Ca and Mg caused by accumulation in closed hydroponic systems may have been beneficial to tomato growth (Hao and Papadopoulos, 2002). This suggested that the standard recommendations for the Ca and Mg nutrition of greenhouse tomatoes in Ontario (Papadopoulos, 1991) might need adjustment. This study was undertaken to investigate the effects of Ca and Mg, and their interactions, on plant growth, biomass partitioning, and fruit yield for optimizing the mineral nutrition of greenhouse tomato grown in winter.

Materials and Methods

Two winter experiments were conducted at the Greenhouse and Processing Crops Research Centre, (GPCRC), Agriculture and Agri-Food Canada, Harrow (41 °N), Ontario, Canada. The experiments were conducted in two double-inflated polyethylene greenhouses (45 m² each) from September 1997 to January 1998, and from September 1998 to January 1999, respectively.

‘Trust’ tomato seeds were sown in small rockwool cubes (3.8 × 3.6 × 4.0 cm, Pargro Inc., Orillia, Ont., Canada) in seedling packs. After cotyledons became fully unfolded, the seedlings were transplanted into large rockwool blocks (7.5 × 7.5 × 7.5 cm; Pargro Inc., Orillia, Ont., Canada). The transplants were raised on benches and flood irrigated using a Harrow Fertigation Manager (Climate Control Systems Inc., Leamington, Ontario, Canada) according to standard nutrient recommendations (Papadopoulos, 1991; Papadopoulos and Liburdi, 1989).

On 11 Sept. 1997 and 18 Sept. 1998, at the four- to five-leaf stage, transplants were transferred onto sleeved rockwool slabs (90 × 15 × 7.5 cm, Pargro Inc., Orillia, Ont., Canada) in the greenhouses, at a 3 plants m⁻² plant population. Day/night heating temperature was set at 19/18 °C while ventilation temperature was set at 23 °C. Day/night relative humidity was set at 70%/65%. Plants were trained to a single stem according to commercial practices. An electrical vibrator was used to assist flower pollination daily. The plants were drip-irrigated with appropriate nutrient solutions. To avoid nutrient buildups in the rockwool, 20% to 30% extra nutrient solution was applied (Papadopoulos, 1991). The plants were topped on 1 Dec. 1997, and 3 Dec. 3 1998, respectively.

Nutrient treatments. In both experiments, six nutrient treatments were applied as a factorial combination of two Ca concentrations (150 and 300 mg·L⁻¹) and three Mg concentrations (20, 50, and 80 mg·L⁻¹). In each polyethylene greenhouse, 8 rows of plants were grown. Two side rows were used as guard rows while the

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other six rows were used as treatment rows. There were nine plants in each treatment row (plot). The plant at either end of the treatment row was treated as a guard plant. Therefore, data were only collected from seven plants in each plot. The treatments were replicated four times over 2 years. Each treatment plot was fed with an independent irrigation system.

Nitrogen (185 mg·L⁻¹ NO₃-N and 15 mg·L⁻¹ NH₄-N), phosphorus (50 mg·L⁻¹), potassium (390 mg·L⁻¹), iron (7 mg·L⁻¹), manganese (0.8 mg·L⁻¹), zinc (0.16 mg·L⁻¹), copper (0.05 mg·L⁻¹) and boron (0.52 mg·L⁻¹) were used in all nutrient treatments. To equalize the EC of nutrient solution across treatments (to avoid confounding the effects of Ca and Mg with EC), the concentration of chloride (Cl⁻), sulphate (SO₄²⁻) and sodium (Na⁺) were allowed to vary in the range of 100 to 150 mg·L⁻¹, 280 to 450 mg·L⁻¹, and 40 to 80 mg·L⁻¹, respectively. The variation of Cl⁻, SO₄²⁻ and Na⁺ within those ranges of concentration does not have any significant effect on greenhouse tomatoes (Lopez et al., 1996; Nukaya and Hashimoto, 2000; Voogt and Sonneveld, 1997). The final EC for all the nutrient treatments was 3 ± 0.2 mS·cm⁻¹ while the pH was adjusted to 5.8 by adding nitric acid.

Leaf chlorophyll, plant growth, and biomass. Plant leaf dry weight, and stem dry weight were measured at the end of the experiment. All leaves removed from the plants during the experiments were saved, and their dry weights measured and recorded. Fruit dry matter content was assessed monthly, and unharvested fruit dry matter content was determined at the

end of the experiments. Each time, five to six fruit were sampled from each plot. Fruit dry weight was determined after drying at 65 °C for 3 weeks. The plant leaf dry weight, stem dry weight data plus the data on yield and fruit dry matter content were used to estimate biomass partitioning. Leaf chlorophyll was estimated with a SPAD-502 leaf chlorophyll meter (Minota, Osaka, Japan) on the 5th, 10th, 15th, 20th, and 25th leaf (counted from the top leaf longer than 10 cm). Leaf Mg and Ca deficiency symptoms were monitored weekly. The date of the first appearance of symptoms and a visual estimate of the percentage of leaf area with the symptoms were recorded.

Fruit harvest and grading. Fruit reaching breaker stage were harvested two to three times a week from 13 Nov. 1997 to 26 Jan. 1998 and from 19 Nov. 1998 to 18 Jan. 1999. Harvested fruit were graded according to commercial grading standards (Ontario Ministry of Agriculture and Food, Regulation 378/90, 1987). Unmarketable fruit were divided into blossom-end rot (BER) and catfaced (CF) and other unmarketable.

Data analysis. Data were analysed with the SAS General Linear Model Procedure (GLM). The data from the 2 years were combined before analysis of variance was conducted. If the treatment effects were significant in the analysis of variance, then their means were separated with Duncan’s multiple-range test. A polynomial model was used for regression analysis on Mg concentrations when the *P* value for the Mg effect in the analysis of variance was <0.20. The regression model was fitted

with a backward elimination method and *P* value of 0.15 was used to decide whether a model term should be dropped from the model during the fitting process. The partial *R*² (*R*²_{Mg}), which measured the strength of the relationship between the response variable and Mg concentration after adjustment for CA and replication (block) effects, was calculated for the final regression. Significance of the *R*²_{Mg} was determined by an F test (Hao, 1995): $F = ((R^2_{Mg})((error - df)/((1 - R^2_{Mg})(Mg - df)))$ with *Mg* – *df*, *error* – *df*, where *Mg* – *df* was the degrees of freedom for all Mg terms, and *error*-*df* was the degrees of freedom for error. Only the final regression functions that were significant (*P* < 0.05) are reported.

Results and Discussion

Plant growth and leaf chlorosis. Plants started to show symptoms of Mg deficiency (leaf chlorosis) 8 weeks after planting, when the plants were ≈1.5 m in height in the two experiments. Treatment 300/20 (Ca/Mg, mg·L⁻¹) showed first and most severe Mg deficiency symptoms (Table 1). Treatments 150/50, 150/80, 300/80 (Ca/Mg) showed little or no symptoms of Mg deficiency. There were no visible leaf Ca-deficiency symptoms in the two experiments.

The Mg-deficiency symptoms appeared not only on bottom leaves (Table 1), but also on the top and middle leaves. In contrast to common opinion, the most severe Mg-deficiency symptoms occurred on the upper middle leaves instead of the bottom leaves. The

Table 1. Leaf greenness of tomato plants grown at different Ca and Mg concentrations in 1998–99. Leaf greenness was measured with a SPAD 502 leaf chlorophyll meter on 4 Nov., 7 Dec., and 21 Dec., 1998 and 6 Jan. 1999 for leaf 5, 10, 15, 20, and 25. Leaf position was counted from the top leaf longer than 10 cm. There was no significant difference (*P* > 0.15) among treatments on 4 Nov. and for leaf 25 in all the measurements. The data presented are means of three plants. Means followed by different letters are significantly different (*P* < 0.05).

Ca and Mg (mg·L ⁻¹)	Leaf position											
	7 Dec. 1998				21 Dec. 1998				6 Jan. 1999			
	5th	10th	15th	20th	5th	10th	15th	20th	5th	10th	15th	20th
150 and 20	35.8 a	27.4 abc	29.5 ab	31.7 ab	37.1 a	16.3 c	22.0 a	28.2 a	25.2 abc	16.5 b	23.3 b	35.0 a
150 and 50	36.9 a	34.0 a	34.1 a	30.9 ab	33.0 a	33.6 a	31.4 a	35.8 a	25.4 abc	30.8 a	34.1 a	33.1 ab
150 and 80	35.4 ab	34.0 a	34.0 a	34.6 a	33.6 a	34.7 a	35.6 a	33.6 a	35.6 a	33.7 a	32.6 a	34.9 a
300 and 20	28.8 b	22.9 c	26.2 b	28.6 b	25.3 a	11.8 c	23.0 a	29.9 a	17.6 c	9.8 b	18.9 c	26.7 b
300 and 50	34.6 ab	26.6 bc	31.7 a	27.2 b	31.2 a	21.3 b	28.9 a	28.5 a	23.9 bc	16.4 b	27.2 b	29.1 ab
300 and 80	35.2 ab	32.9 ab	32.8 a	33.8 a	35.0 a	33.0 a	33.5 a	32.0 a	33.6 ab	30.0 a	32.7 a	33.1 ab
Interaction												
Ca	NS	*	NS	*	NS	**	NS	NS	NS	**	**	*
Mg	NS	**	**	**	NS	**	NS	NS	*	**	**	NS
Ca × Mg	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	*	NS
Regression against Mg (mg·L ⁻¹)	Ca (mg·L ⁻¹)				<i>R</i> ²							
7 Dec.												
10th	150, 300				22.73 + 0.1381X				54.9**			
15th	150, 300				22.77 + 0.0928X				45.2**			
20th	150, 300				34.40 – 0.2822X + 0.0035X ²				56.5*			
21 Dec.												
10th	150				–4.26 – 1.2047X + 0.8972 × 10 ⁻² X ²				99.6**			
10th	300				4.31 + 0.3542X				97.7**			
15th	300				19.72 + 0.1733X				79.5*			
6 Jan.												
5th	300				11.64 + 0.2675X				88.4*			
10th	150				12.63 + 0.2867X				78.6*			
10th	300				1.83 + 0.3375X				93.4**			
15th	150				9.24 + 0.84X – 0.0069X ²				99.1**			
15th	300				14.77 + 0.23X				93.8**			
20th	300				24.28 + 0.1067X				88.4*			

NS,*,**The effect was nonsignificant (*P* > 0.05), significant (0.01 < *P* < 0.05), or highly significant (*P* < 0.01), respectively.

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Table 2. Biomass and biomass partitioning of tomato grown at different Ca and Mg concentrations in 1997 and 1998. The means presented are averages of 2 year data. Means followed by different letters are significantly different ($P < 0.05$). The P value for Mg effect on biomass and biomass allocation to fruit (%) was 0.07 and 0.09, respectively.

Ca and Mg (mg·L ⁻¹)	Biomass (g/plant)	Fruit dry mass (g/plant)	Biomass allocation (%)			
			Fruit	Stem	Leaf	Root ^z
150 and 20	310.3 b	169.7 b	54.8 b	12.4 a	30.3 ab	2.8 a
150 and 50	350.1 ab	197.8 ab	56.5 ab	12.2 a	28.6 bc	2.6 a
150 and 80	327.9 ab	186.3 ab	56.8 ab	12.2 a	28.2 bc	2.8 a
300 and 20	322.0 b	174.2 b	54.1 b	11.7 a	31.2 a	2.9 a
300 and 50	345.7 ab	197.7 ab	57.2 ab	11.3 a	28.6 bc	2.9 a
300 and 80	380.6 a	223.7 a	58.8 a	11.2 a	27.3 c	2.7 a
Interaction						
Ca	NS	NS	NS	*	NS	NS
Mg	NS	*	NS	NS	*	NS
Ca × Mg	NS	NS	NS	NS	NS	NS
Regression against Mg (mg·L ⁻¹) ^y	Ca (mg·L ⁻¹)		R^2			
Biomass (g/plant)	150	$253.51 + 3.7262X - 0.0343X^2$		81.9**		
Fruit dry matter (g/plant)	150	$129.57 + 2.4800X - 0.0220X^2$		53.8*		
	300	$157.21 + 0.8265X$		42.9*		
Partition to fruit (%)	150	$52.75 + 0.0789X$		66.6**		
Partition to leaves (%)	300	$32.32 - 0.0654X$		65.5**		

^zCollectable roots from the underside of the rockwool slabs.
^yThe regression of biomass on Mg concentration at 300 mg·L⁻¹ Ca was $293.78 + 0.9757X$ with a P value = 0.077.
NS,*,***The effect was nonsignificant ($P > 0.05$), significant ($0.01 < P < 0.05$), or highly significant ($P < 0.01$), respectively.

Table 3. Fruit yield, size and blossom-end rot (BER) of tomato grown at different Ca and Mg concentrations in 1997 and 1998. The means presented are averages of 2 year data. Means followed by different letters are significantly different ($P < 0.05$). The P value for the Mg effect on total fruit weight was 0.07. The P value for the Ca effect on marketable yield was 0.1.

Ca and Mg (mg·L ⁻¹)	Total fruit wt (kg/plant)	Marketable yield (kg/plant)	Marketable fruit size (g/fruit)	Marketable ^z fruit wt (%)	BER ^z fruit wt (%)
150 and 20	3.63 b	3.48 b	125.6 a	95.6 ab	1.78 c
150 and 50	4.13 ab	3.77 ab	130.4 a	91.2 bc	4.73 b
150 and 80	3.88 ab	3.47 b	126.8 a	89.3 c	7.12 a
300 and 20	3.69 b	3.53 b	128.5 a	95.5 ab	0.83 c
300 and 50	4.01 ab	3.91 ab	125.4 a	97.4 a	0.50 c
300 and 80	4.43 a	4.23 a	133.2 a	95.3 ab	0.92 c
Interaction					
Ca	NS	NS	NS	**	**
Mg	NS	NS	NS	NS	NS
Ca × Mg	NS	NS	NS	NS	NS
Regression against Mg (mg·L ⁻¹) ^y	Ca (mg·L ⁻¹)		R^2		
Total fruit weight (kg plant ⁻¹)	150	$2829.83 + 45.6185X - 0.4160X^2$		47.3*	
	300	$3429.82 + 12.3501X$		45.5*	
Marketable fruit (%)	150	$97.26 - 0.1046X$		54.4*	
BER fruit (%)	150	$0.0993 + 0.0889X$		47.9*	

^zPercentage over total fruit weight.
^yThe regression of marketable yield on Mg concentration, at 300 mg·L⁻¹ Ca was $3310.81 + 11.6106X$ with a p -value = 0.07.
NS,*,***The effect was nonsignificant ($P > 0.05$), significant ($0.01 < P < 0.05$), or highly significant ($P < 0.01$), respectively.

chlorophyll of the 10th and 15th fully expanded leaf, at middle to late growth stages, increased with increasing Mg concentration (Table 1), especially at 300 mg·L⁻¹ Ca. The occurrence of Mg deficiency on the middle leaves was also found by Sonneveld and Voogt (1991) in a fall greenhouse tomato crop. In this study, even at 50 mg·L⁻¹ Mg (the recommended Mg level, Papadopoulos, 1991), the chlorophyll content of the 10th fully expanded leaf was significantly lower than at 80 mg·L⁻¹ when Ca was applied at 300 mg·L⁻¹ (Table 1). The occurrence of Mg-deficiency symptoms on the upper-middle leaves could significantly affect the photoassimilate production and supply to other parts of the plants.

There was a significant interaction between Ca and Mg on the chlorophyll content of the 10th fully expanded leaf on 21 Dec. 1998 and 6 Jan. 1999 (Table 1). High Ca (300 mg·L⁻¹)

increased the probability of leaf chlorosis (Table 1), most likely through its competition with Mg for uptake, which was reflected by a stronger response of the leaf chlorophyll loss to low Mg concentrations at 300 mg·L⁻¹ Ca. The antagonism between Ca and Mg for uptake in tomato is well known (Ho et al., 1999; Paiva et al., 1998).

Biomass and biomass partitioning. At 300 mg·L⁻¹ Ca, total fruit dry matter increased linearly with increasing Mg concentration while biomass partitioned to leaves decreased linearly with increasing Mg concentration (Table 2). Total plant biomass at 300 mg·L⁻¹ Ca also increased with increasing Mg concentration as total fruit dry matter but in a smaller magnitude. Presumably the increase in biomass partitioned to fruit indicated a higher leaf photosynthetic capability and higher export of carbohydrates from leaves (per unit weight) at high Mg concentration. At

150 mg·L⁻¹ Ca, total biomass and total fruit dry matter production were the highest at 50 mg·L⁻¹ Mg, and the percent of the biomass partitioned to fruit also increased linearly with increasing Mg concentration. High Ca (300 mg·L⁻¹) reduced biomass partitioning to the stem.

Fruit yield and grades. Total and marketable yield at 20 mg·L⁻¹ Mg was lowest regardless of Ca concentration (Table 3). Marketable yield at 150/80 mg·L⁻¹ Ca/Mg was reduced due to a high BER incidence. At 300 mg·L⁻¹ Ca, total fruit weight increased linearly with increasing Mg concentration while it showed a quadratic response to Mg concentration at 150 mg·L⁻¹ Ca. At 150 mg·L⁻¹ Ca, total fruit weight was the highest at 50 mg·L⁻¹ Mg. Marketable fruit yield showed similar but weaker response. The percentage of BER fruit increased linearly with increasing Mg concentration at 150 mg·L⁻¹ Ca while it was not affected by Mg concentration

Fig. 1. Monthly marketable fruit yield at different Ca and Mg ($\text{mg}\cdot\text{L}^{-1}$) concentrations in 1997 and 1998. The different letters above the bars indicate a significant difference ($P < 0.05$); Duncan's multiple range test.

at $300\text{ mg}\cdot\text{L}^{-1}$ Ca. The increase in BER with high Mg at 150 ppm Ca resulted in a linear reduction in the percentage of marketable fruit, and a significantly lower marketable fruit yield at $150/80\text{ mg}\cdot\text{L}^{-1}$ Ca/Mg than at $300/80\text{ mg}\cdot\text{L}^{-1}$ Ca/Mg. The BER incidence at $300\text{ mg}\cdot\text{L}^{-1}$ Ca, at all Mg treatments, was quite low. High Ca reduced the BER incidence and increased the percentage of marketable fruit. There was no significant Ca or Mg effect on marketable fruit size and fruit distribution in other grades (Table 3).

High Mg concentration did not offer any advantage over low Mg concentration in early fruit production (Fig. 1). There was no significant difference in the marketable yield from the first month of fruit harvest (before Dec. 19) among various Mg concentrations regardless of Ca concentration. However, the marketable yield in the second month (after 19 Dec.) of fruit harvest significantly increased with Mg concentration at the $300\text{ mg}\cdot\text{L}^{-1}$ of Ca. The difference in response to Mg concentration might be due to two factors: light and plant physiological age. Monthly average daily solar radiation during the 1997 experiment was 14.6 , 11.8 , 5.4 , 4.2 , and $4.3\text{ MJ}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ for September 1997 to January 1998, respectively. The monthly average daily solar radiation during the 1998 experiment was 16.8 , 10.4 , 6.4 , 5.8 , and $6.1\text{ MJ}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ for September 1998 to Janu-

ary 1999, respectively. It usually takes 6 to 8 weeks from fruit set to ripening in greenhouse tomato. Therefore, the fruit harvested in the first month developed under much stronger solar radiation than those harvested in the second month. Magnesium is a major component of chlorophyll, which is critical for the light reaction of photosynthesis. Under limiting light conditions, such as those in the last 2 months of our experiments, reduction of light reaction efficiency with low chlorophyll caused by low Mg concentration could have significantly reduced the photo-assimilate production, and thus caused a concomitant yield reduction. In a study conducted on a fall greenhouse crop on rockwool, Sonneveld found (1987) that root Mg uptake capability of tomato roots declined as the plant aged. This indicates that the supply of Mg to tomato plants may need to be increased towards late growth stages. For both above discussed reasons, it would appear appropriate that the supply of Mg in a winter tomato crop be increased towards the latest growth stages.

In conclusion, high Ca ($300\text{ mg}\cdot\text{L}^{-1}$) reduced the BER incidence. Low Mg (20 ppm) reduced leaf chlorophyll in middle leaves and reduced fruit yield in late fruit production. Fruit biomass and total fruit yield increased linearly with increasing Mg concentration at $300\text{ mg}\cdot\text{L}^{-1}$ Ca. Total plant biomass and marketable fruit yield at $300\text{ mg}\cdot\text{L}^{-1}$ Ca showed similar but weaker response. At $150\text{ mg}\cdot\text{L}^{-1}$ Ca, total plant biomass and fruit yield peaked at $50\text{ mg}\cdot\text{L}^{-1}$ Mg. Magnesium effects on total and marketable fruit yield were mainly due to their influence on late fruit yield. There was little difference in fruit yield among treatments in early fruit production. High Mg increased fruit BER incidence at $150\text{ mg}\cdot\text{L}^{-1}$ Ca. Therefore, for a winter greenhouse tomato crop, the appropriate Ca and Mg concentrations for tomato production appear to be at 300 and $80\text{ mg}\cdot\text{L}^{-1}$, respectively.

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