Response of "Jonagold" apple trees to Ca, K and Mg fertilization in an andisol in southern Chile

E. von Bennewitz[1*], T. Cooper[2], C. Benavides[2], T. Losak[3], J. Hlusek[3]

[1]*Department of Agronomy, Universidad Católica del Maule, Casilla 7-D, Curicó, Chile.*[2]*Department of Plant Production, Universidad de Chile, Av. Santa Rosa 11315, La Pintana Santiago, Chile.* [3] *Department of Agrochemistry, Soil Science, Microbiology and Plant Nutrition, Mendel University in Brno, Zemedelská 1, 61300 Brno, Czech Republic.*Corresponding author: evon@ucm.cl*

Abstract

The effects of Ca, Mg and K fertilisation on the growth, yield, fruit quality and mineral concentration of the fruits and leaves of "Jonagold" apple trees that were grown in an Andisol in southern Chile were analysed. In general, the Andisols in this area contain low reservoirs of these elements; therefore, the roles of these elements as essential macroelements and their effects on plant growth, yield and fruit quality are key factors that should be considered in these soils in current and future apple orchards. The soil application of Ca, Mg and K ($CaSO_4$, $MgSO_4$ and K_2SO_4) did not significantly affect vegetative growth, fruit production or their quality parameters. Ca and Mg fertilisation did not affect the uptake at the present stage of development and production. The mineral concentration of K in the leaves was significantly increased in the plants that were treated with K alone (1.67% DW) or in combination with Ca and Mg (1.8% DW). The fertilisation did not result in the development of physiological disorders in the fruit. This study revealed no relationships between the apple nutrient status and the Ca, Mg and K saturation ratios in the soil. However, the medium to low exchangeable content of these elements in the soil may affect the yields and the quality of the fruit in the future due to the increased demand by the trees for those elements.

Keywords: *Malus domestica*, fruit physiological disorders, volcanic soils, Ca, Mg, K.

1. Introduction

Many of the traditional Chilean apple-growing areas, which are concentrated in the central and central-south zone of the country, are expected to suffer alterations in their growing conditions in the next few decades as a result of climate change (Neuenschwander, 2010). These modifications could include the following: a rise in summer temperatures, a decrease in chill unit accumulation, and a decrease in the availability of irrigation water resources. The resulting altered climatic conditions may create complex scenarios in which a decrease in the fruit yield and quality and an increase in the incidence of pests and diseases could be expected. However, the warming of the climate will facilitate the expansion of the commercial production of apples in many areas of southern Chile. Therefore, a change in the apple-cultivated areas towards the southern part of the country could be expected. This southward migration of the traditionally cultivated areas towards new ones will require knowledge of the particular soil properties and features and the effects of the soil on growth, fruit yield and quality.

Among the different groups of soils that are present in southern Chile, the volcanic soils contain some of the most important features in terms of their area and productive potential (Sierra, 1982; Benavides, 1992). These soils contain some characteristic chemical features, which generally include a low reservoir of calcium (Ca), magnesium (Mg) and potassium (K) (Benavides, 1992). These macroelements are essential for plant nutrition, and their effects on plant growth, yield and fruit quality are key factors that must be considered in current and future apple orchards. Many studies have emphasised the importance of the relationship between apple tree nutrition and the production of fruit quality (Faust, 1989; Kysiak and Pacholac, 1994). Among the macroelements, Ca and K are two of the nutrients that most obviously influence fruit quality (Faust, 1980). Calcium is especially important for apples because they are stored for long periods of time, and other factors cannot substitute for the effects of Ca on storage quality (Tomala, 1997). Apple fruits that contain low Ca concentrations are sensitive to many physiological disorders, such as bitter pit, internal breakdown, cork spot, water core, and disease (Fallahi *et al*., 1997). Therefore, the proper nutrient balance is essential for maintaining the fruit quality in apples (Dris *et al*., 1999). For example, an increase in the potassium to calcium ratio has been reported to increase the occurrence of fruit disorders (Casero *et al*., 1989; Tomala, 1997).

This research analysed the effects of Ca, Mg and K fertilisation on the growth, yield, fruit quality and mineral concentration of the fruits and leaves of "Jonagold" apple trees that were cultivated in an Andisol in southern Chile and fertilised with base cations (Ca, Mg and K).

2. Materials and methods

The study was conducted on an Andisol in Southern Chile (39.31ºS, 72. 59ºW, 36 m.a.s.l). The soil at the site belongs to the Pelchuquin soil Series (Eutric Fulvudands) (Salazar *et al*., 2005), and it displays a silt loam texture at the 0-20 cm soil layer. The soil chemical properties were determined at the beginning of the study by considering two of the soil layers (0-20 cm and 20-40 cm). The analyses were performed according to the methods that were described by Sadzawka et al. (2000). At the two soil depths (0-20 cm and 20-40 cm), the soil contained high organic matter contents (21.6% and 30.0%, respectively) and a strongly acidic soil reaction (pH $CaCl_2$ values of 5.14 and 4.8) (Table 1).

Table 1. Soil chemical properties of the experimental site.

Properties	Soil layer	
	0-20 cm	20-40 cm
OM (%)	21.61	30.00
pH (H_20)	5.35	5.40
pH ($CaCl_2$)	5.14	4.80
Olsen P (mg kg^{-1})	27.00	7.00
Al (cmolc kg^{-1})	0.36	0.00
Al saturation (%)	5.60	0.00
Ca (cmolc kg^{-1})	4.41	2.93
Ca saturation (%)	69.00	73.43
Mg (cmolc kg^{-1})	0.66	0.54
Mg saturation (%)	10.00	13.53
K (cmolc kg^{-1})	0.66	0.31
K saturation (%)	9.00	7.90

The study site displays a temperate, rainy climate with Mediterranean influences. During the summer months, the average temperature is approximately 17 °C, while in the winter, the temperature declines to 9 °C. The annual average temperature is 11 °C, the mean temperature amplitude is 8.8 °C and the daily amplitude is 11°C. The average annual precipitation is 2593 mm, which is distributed throughout the year, but it primarily occurs between March and October.

The plant material consisted of five-year-old "Jonagold" apple trees. The trees were grafted onto apple seedlings, spaced 5 × 5 m apart in north-to-south rows and trained to a vertical axis system. The trees were irrigated weekly with under-tree microsprinklers in the southern hemisphere summer from December to late March. The orchard practices included the mechanical cultivation between the rows and weed control with herbicides within the tree rows. The pruning was similar in all of the treatments. The trees were selected based on their uniform vigour and development.

The fertilisation treatments consisted of different combinations of Ca, Mg and K that were ground applied over 30-cm-wide strips that surrounded the tree drip line. The fertilisers were incorporated with irrigation water. The nutrients were applied at rates of 200 kg ha^{-1} for each of their oxides (CaO, K_2O and MgO). The fertiliser sources consisted of $CaSO_{4,}$ $MgSO_4$ and $K_2SO_{4.}$ The total doses were divided into two equal doses that were applied in early and mid-spring. The treatments are presented in table 2.

Table 2. Rates and combinations of Ca, Mg and K fertilisation expressed as oxides and commercial fertilisers.

Treatment	Nutrient		(kg ha^{-1})	Commercial fertilisers (kg ha^{-1})		
	CaO	K^2O	MgO	$CaSO^4$	$MgSO^4$	$K2SO^4$
Control	0	0	0	0	0	0
Ca	200	0	0	624	0	0
Mg	0	0	200	0	0	1248
K	0	200	0	0	400	0
Ca+Mg	200	0	200	624	0	1248
Ca+K	200	200	0	624	400	0
Mg+K	0	200	200	0	400	1248
Ca+Mg+K	200	200	200	624	400	1248

The following vegetative growth measurements and observations were performed:

For the trunk cross-sectional area (TCSA), the trunk circumference (C) was measured 20 cm above the soil line, and the TCSA was calculated using the following formula: TCSA=C2/4Π. The scaffold branches extension growth was measured in two scaffold branches that were situated in the middle of the height of the tree. For shoot growth, the extension growth of the seasonal shoots and scaffold branches were measured in two marked shoots (> 50 cm) and scaffold branches per tree.

The fruits were harvested according to Streif's index [firmness/(percentage soluble solids concentration x starch index)].

2.1. Fruit analyses

The fruits were harvested when Streif's index indicated values over 6. The fruit yield was measured separately for each tree, and the fruits were classified according to their diameter into three different size groups: small=< 70 mm, medium=70-80 mm and large = > 80 mm. The firmness was measured on 12 fruits per tree using a McCormick firmness tester with an 11-mm tip on the blush and the opposite side of each apple. The soluble solids concentration percentage (SSC) was determined using an Atago-1 hand-held refractometer with automatic temperature compensation at 22°C in juice that was squeezed from the homogenate of the 12 fruits that were sampled for flesh firmness. The starch index of the fruit was estimated by the iodine test using a scale of 1 (100% of the cross-section area was stained) to 10 (0% of the area was stained), the fruit ground colour was measured using a 1 to 6 scale (Winter *et al*. 1981) and the fruit cover colour was measured using a scale from 1 (blush <25% of the fruit skin surface) to 5 (blush >76% of the skin surface). The flesh firmness and SSC of the fruit after storage were measured on 12 fruits per tree. The apple fruits were stored for 60 days in refrigerated air storage at 1-2°C and a relative air humidity of 88–90%. The measurements were performed after the fruits were removed from storage, and they were then kept at room temperature at 18-20°C for 5 days. The incidence of physiological disorders and diseases were assessed on the 12 fruits per tree at the same time as the firmness and SSC were assessed. The concentrations of N, P, K, Mg and Ca in the fruit tissues were determined as follows. The fruits were collected at harvest. Three fruits from each tree were randomly collected from the central zone of the tree crown. Apples of a similar diameter were rinsed with 0.01 M HCl and then with double-deionised water. The seeds and stems were removed, and two quarters of the apple were cut out from opposite sides. The fruit samples were dried at 75°C for 72 h and ground to pass through a 40-mesh screen. The level of nitrogen was determined according to the Kjeldahl method. To determine the levels of P, K, Ca, and Mg, the fruit samples were digested in a 9:1 (v:v) mixture of HNO_3. Potassium, Mg and Ca were determined with an atomic absorption spectrometer, and P was determined colorimetrically by the vanado-molybdo-phosphoric method. The concentration of the nutrients in the fruit tissues was expressed in relation to the dry weight (DW).

2.2. Leaf analysis

The leaves were collected from the mid-region of current season shoots after the terminal bud formed in mid-January. The leaves were washed in detergent, rinsed in deionised water, dried at 65°C, and ground in a grinder. A set digestion was used for the organic matter destruction in the case of N, P, K, Ca and Mg, and dry ashing was used for Fe, Mn, Cu and Zn. The same methods of nutrient detection following the digestion were used for the fruits.

The data were subjected to an analysis of variance (ANOVA) in a completely randomised design that contained eight treatments and ten replicates per treatment (1 replicate=1 tree). The mean separation was performed by Duncan"s multiple range test at the 5 and 1% levels of significance. The statistical procedures were performed using the SAS software. The percentage of the fruit diameter distribution, the apples with physiological disorders and diseases and the fruit colour were calculated following the data transformation that was performed according to Bliss"s function (y=arc sinx)

3. Results and discussion

The trunk cross-sectional area (TCSA) and the extension growth of the seasonal shoots and scaffold branches were not affected by the treatments (Table 3).

Table 3. Trunk cross-sectional area (TCSA) and the extension growth of the seasonal shoots and scaffold branches of five-year-old "Jonagold" apple trees.

Treatments	TCSA 1994 (cm^2)	TCSA 1995 (cm^2)	Increment of TCSA (cm^2)	Shoot growth Growth (cm)	Scaffold Branches (cm)
Control	96.4a	143.2a	46.8a	33.4a	42.5 a
Ca	89.8a	132.2a	42.4a	28.4a	30.9 a
Mg	92.5a	135.6a	43.1a	33.6a	46.2 a
K	93.1a	133.5a	40.4a	37.4a	45.6 a
Ca+Mg	78.9a	115.2a	36.2a	43.4a	38.1 a
Ca+K	92.5a	140.4a	47.9a	36.6a	35.5 a
Mg+K	95.3a	123.5a	28.2a	34.3a	34.8 a
Ca+Mg+K	86.1a	126.8a	40.7a	31.8a	37.5 a

Different letters within the rows indicate significant differences ($p \leq 0.05$).

The mean values for these three measurements reflected a moderate vigour for this cultivar. We could therefore expect that the trees were adequately supplied with both the carbohydrates and the nutrients that were required for the extension growth.

The "Jonagold" apple tree cropping was not influenced by the treatments (Table 4), and it averaged 77.6 kg/tree, which is equivalent to 31 ton/ha and can be considered a very good yield compared to the yields of 22.5 kg/tree that were obtained in the dense "Jonagold" orchards of the same age and rootstock in Germany (Stehr and Clever, 1995). The treatments also did not affect the fruit diameter distribution (Table 4). Of the fruit yield, 55% was concentrated in the medium size group (70-80 mm of fruit diameter), which commanded the best prices, followed by the large (> 80 mm, 26.17%) and the small (<70 mm, 21.24%) sizes.

Table 4. Effects of Ca, Mg and K fertilisation on the "Jonagold" apple yield and fruit diameter distribution.

Treatment	Fruit diameter (mm)						Yield	
	(>80)	(%)	(70-80)	(%)	(<70)	(%)	Total (kg/tree)	Yield/TCSA (kg cm^{-2})
Control	17.5a	28.9a	36.6a	55.9a	10.7a	15.0a	66.8a	0.47aa
Ca	21.4a	26.5a	46.3a	55.6a	16.1a	17.8a	83.9a	0.63a
Mg	19.3a	23.5a	44.8a	52.9a	19.6a	23.4a	83.8a	0.62a
K	16.7a	26.0a	38.8a	62.4a	19.4a	31.5a	75.0a	0.56a
Ca+Mg	22.8a	28.9a	42.5a	51.4a	16.9a	19.6a	82.3a	0.71a
Ca+K	20.6a	24.9a	44.0a	52.0a	20.3a	23.0a	85.0a	0.61a
Mg+K	19.8a	27.0a	43.7aA	55.4a	14.6a	17.5a	78.1a	0.63a
Ca+Mg+K	17.0a	23.3a	34.2 a	54.7a	14.5a	21.8a	65.8a	0.52a

Different letters within the rows indicate significant differences ($p \leq 0.05$).

The fruit firmness, soluble solids, ground colour and starch index were not affected by the treatments (Table 5).

Table 5. Effects of Ca, Mg and K fertilisation on the "Jonagold" apple quality parameters that were determined at harvest and after 60 days of storage.

Treatment	Fruit firmness (kg)		Soluble solids Brix (%)		Ground colour (1-6)		Starch index (1-10)	
	Harvest	60 days	Harvest	60 days	Harvest	60 days	Harvest	60 days
Control	7.4a	4.9a	13.2a	13.4a	5.6a	6.0a	9.6a	10.0a
Ca	7.2a	4.9a	12.7a	13.5a	5.6a	6.0a	9.8a	10.0a
Mg	7.4a	4.7a	12.3a	13.2a	5.6a	6.0a	9.6a	10.0a
K	7.4a	4.9a	12.9a	13.4a	5.6a	6.0a	9.5a	10.0a
Ca+Mg	7.4a	4.8a	12.6a	13.3a	5.6a	6.0a	9.7a	10.0a
Ca+K	7.2a	4.9a	13.3a	13.3a	5.6a	6.0a	9.6a	10.0a
Mg+K	7.4a	4.9a	12.8a	13.6a	5.5a	6.0a	9.5a	10.0a
Ca+Mg+K	7.6a	4.9a	13.4a	13.3a	5.5a	6.0a	9.6a	10.0a

Different letters within the rows indicate significant differences ($p \leq 0.05$).

The concentration of soluble solids increased during the storage period, which was possibly a result of water that was lost from the fruits. An increase in the fruit SSC following storage has been previously reported by some scientists (Shababi and Malakouti, 2000; Tagliavini *et al*., 2000). In general, the apple firmness was very low after 60 days of storage. In this study, the soluble solids concentration was unrelated to the K concentration in the fruits, and the fruit firmness was not related to the K/Ca ratio in the fruits as was reported by Dimalghani *et al*. (2004).

The N, P, K, Ca and Mg concentrations in the fruits was not affected by the treatments (Table 6).

The N concentration in the fruits was adequate according to Shear (1980), who suggested that an N concentration of 0.36 % DW was the limit for the avoidance of physiological disorders, such as bitter pit. The N concentration in the fruit in this study was lower (average 0.19%), and K was the most abundant mineral nutrient in the flesh fruits (average 0.62% DW). Although Ca is likely the most abundant cation that is taken up by apple trees (Tagliavini *et al*., 2000), the levels of Ca that were partitioned into the fruits were relatively small (Table 6). This result is evident when the Ca concentration in the fruits (average 0.03 % DW) is compared with that of the leaves (average 0.95 % DW) (Table 8). Ferguson and Watkins (1989) suggested that a Ca concentration (based on the DW) of 0.002% (flesh) was the minimum concentration that was required for the avoidance of bitter pit (BP), which is the main physiological disorder that is caused by a Ca deficiency. The fruit Ca levels in the current study were over this limit (≥ 0.028% DW), and these results may partially explain the very low incidence of physiological disorders that were associated with Ca in the study fruits.

Table 6. Concentrations of N, P, K, Ca and Mg in the "Jonagold" apple fruits (% DW).

Treatment	N	P	K	Ca	Mg
Control	0.21a	0.038a	0.67a	0.028a	0.029a
Ca	0.19a	0.034a	0.57a	0.030a	0.025a
Mg	0.19a	0.031a	0.61a	0.031a	0.029a
K	0.19a	0.027a	0.67a	0.026a	0.030a
Ca+Mg	0.19a	0.031a	0.57a	0.029a	0.026a
Ca+K	0.18a	0.038a	0.61a	0.036a	0.028a
Mg+K	0.23a	0.038a	0.67a	0.030a	0.030a
Ca+Mg+K	0.18a	0.030a	0.61a	0.031a	0.026a
Mean values	0.19a	0.033a	0.62a	0.030a	0.028a

Different letters within the rows indicate significant differences ($p \leq 0.05$).

The mineral ratios in the "Jonagold" apple fruits were not affected by the treatments (Table 7).

Table 7. Mineral ratios in the "Jonagold" apple fruits as affected by the treatments.

Treatment	N/Ca	K/Ca	Mg/Ca	K+Mg/Ca
Control	7.5	23.9	1.0	24.9
Ca	6.3	19.0	0.8	19.8
Mg	6.1	19.6	0.9	20.6
K	7.3	25.7	1.1	26.9
Ca+Mg	6.5	19.6	0.8	20.5
Ca+K	5.0	16.9	0.7	17.7
Mg+K	7.6	21.7	1.0	23.3
Ca+Mg+K	5.8	19.6	0.8	20.5
Mean values	6.5	20.7	0.8	21.7

Different letters within the rows indicate significant differences ($p \leq 0.05$).

The N/Ca ratios in the fruits were less than 10, which is considered to be an adequate value to ensure a high fruit quality (Faust, 1980; Link, 1992). In the fruit samples, the K/Ca ratio of the control was 23.9, and the mean value was 20.7 (Table 7). Fruit K/Ca ratios that are below 28 have been recommended in Poland (Piestrzeniewicz and Tomala, 2001), and ratios of less than 30 have been recommended in Italy (Drahorad and Aichner, 2001). Therefore, the K/Ca ratio that was observed in the present study seems to be adequate (the highest value was 23.9).

The K+Mg/Ca values were higher than the threshold of 12 that was suggested by Van der Boon (1980) as the limit at which to avoid physiological disorders, such as bitter pit, in the fruits.

Table 8. Effects of Ca, Mg and K fertilisation on the mineral concentrations in the leaves (% DW) of five-year-old "Jonagold" apple trees.

Treatment	N	P	K	Ca	Mg
Control	2.08a	0.11a	1.50a	0.99a	0.16a
Ca	2.09a	0.12a	1.45a	0.99a	0.15a
Mg	2.03a	0.12a	1.27a	0.92a	0.17a
K	2.00a	0.11a	1.67b	0.89a	0.14a
Ca+Mg	2.03a	0.11a	1.35a	1.00a	0.19a
Ca+K	2.05a	0.11a	1.57a	0.98a	0.18a
Mg+K	2.11a	0.11a a	1.57a	0.97a	0.16a
Ca+Mg+K	2.02a	0.12a	1.80b	0.88a	0.16a

Different letters within the rows indicate significant differences ($p \leq 0.05$).

In the year of the study, the leaf mineral concentrations of N, P, Ca and Mg were not significantly affected by the treatments (Table 8). The mineral values reflect the normal levels for N and K and low levels for P, Ca and Mg (Weir and Creswell, 1991). The normal K levels that were measured in this study did not agree with those that were obtained in a survey of the mineral status in fruit trees of the same region that was performed by the Chilean Economic Development Agency (CORFO, 1992). The CORFO study observed low K levels. The low foliar P levels (average 0.11% DW) could be explained by the low Olsen P values (7 mg kg^{-1}) in the 20-40 cm soil layer (Table 1), which is where most of the apple roots are generally concentrated (Faust, 1989). The mineral concentration of K in the leaves was significantly increased in the case of the treatment with K alone (1.67 % DW) or in combination with Ca and Mg (1.8 % DW). The critical Ca threshold value in an apple leaf has been reported to be 1.0 % DW (Weir and Creswell, 1991). In all of the treatments, which include the treatments with Ca, the leaf Ca was under the critical level. This can be explained by the very low mobility of Ca in the plant, and it implies a naturally low uptake of Ca and storage as Ca pectate. The low foliar P levels could be explained based on the low Olsen P values (7 mg kg^{-1}) that were measured in the 20-40 cm layer.

According to these results, the mineral concentrations in the leaves were only affected by the application of ground K in the year of the treatment; Ca and Mg were not observed to cause an effect. This can be explained by the high mobility of K in the trees.

Evidence of the occurrence of bitter pit was only detected after 60 days of storage for the control treatment at a very low level (1.1 on a scale of 1-4). This occurrence did not constitute a significant difference. None of the treatments demonstrated an occurrence of water core, internal breakdown, scald or diseases caused by pathogens, although relatively small amounts of Ca were partitioned into the fruits in the study. Some of the preharvest factors that may explain these favourable results are adequate fruit Mg and K concentrations, adequate crop load and fruit size (Ferguson and Watkins, 1989), N/Ca ratios in the fruits that were less than 10 (Faust, 1980; Link 1992), K/Ca ratios in the fruits that were less than 28 (Piestrzeniewicz and Tomala, 2001), adequate climatic and growth conditions (Quast, 1987) and the fruit storage conditions.

4. Conclusions

Under the climatic conditions of the zone, the "Jonagold" apple trees demonstrated a balanced vegetative growth and were able to produce medium yields of fruit that were of excellent quality and storage capacity.

The Andisol of the study displayed favourable growing conditions for the establishment and development of apple trees.

The soil application of Ca, Mg and K ($CaSO_4$, $MgSO_4$ and K_2SO_4) produced no statistically significant responses of vegetative growth, fruit production or quality parameters. However, the medium to low Ca, Mg and K content in the soil is a factor that may affect the yields and the quality of the fruit in the future, especially considering the increased demand from the trees for those elements. Therefore, the frequent soil applications of Ca, Mg and K should be considered to ensure adequate growth, fruit yield and quality.

The fruits displayed a favourable postharvest behaviour after periods of 60 days of storage, which was determined based on the detection of the very low incidence of physiological disorders that are related to mineral elements and their suitable qualities. Based on the the current level of production and shipments to the USA, this lapse would be sufficient. Nevertheless, the study of the storage capacity of these fruits after prolonged periods should be considered, especially based on the time that is required to transport the fruit to Europe, the intensification of fruit production and the consequent necessity to store the fruit for prolonged periods.

The results that were obtained confirm the possibility of cultivating apple trees in the zone to produce ample quantities of fruits that are destined for export with relatively simple handling and without great disadvantages related to Ca, Mg and K fertility.

This positive scenario reflects favourable climatic, nutritional, orchard management and storage conditions, but additional factors should be considered. Among these factors are the medium to low Ca contents in the leaves and fruits and the high contents of K in the fruits, which are important based on the antagonistic relationship between these elements.

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