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Response of French Bean (*Phaseolus vulgaris* L.) Cultivars to Foliar Applications of Magnesium

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Abstract

Magnesium deficiencies have been shown to be particularly dangerous to short cycled crops, both on sandy and clay soils. Such deficiencies may be corrected by foliar fertilisations, but in French bean (*Phaseolus vulgaris* L.) no experimental data may be found to support this hypothesis. Therefore this paper was aimed at studying the effect of foliar Mg-applications (56, 112 and 224 g ha^{-1} in single application at flowering or splitted half dose at 4-leaf stage and half at flowering) alone and with Zn (200 g ha^{-1}) on yield and quality of two French bean genotypes (Bronco, Cadillac).

Foliar Mg-applications significantly increased pod yield and, considering the highest rate with respect to the untreated, such an increase was 78% and 32% for Bronco and Cadillac, respectively. Split applications were also more effective, with yield increases of 109% and 50% for the two genotypes. Concerning quality, foliar Mg applications showed a significant effect particularly on sugars, calcium, phosphate, sulphate and Mg contents in pods. On the other hand, a significant effect on the accumulation of nitrates was noted, especially with split applications (144% increase vs. unfertilised) and, in some cases, an antagonistic effect on K content (10-20% decrease on average).

Foliar Mg fertilisation of French bean seemed to be a promising practice with reference to human health and nutrition, tough some care is needed to avoid the accumulation of nitrates in pods. Split applications seemed to be more effective, while the addition of Zn to the fertiliser mix did not give any relevant effect.

Key-words: fertilisation, fruit quality, microelements, magnesium, French bean.

1. Introduction

Magnesium plays an important role in plant metabolism and physiology, as it is a component of the chlorophyll molecule and it is required for normal structural development of chloroplasts and other organelles such as the mitochondria, where it is the bridging element for ribosome aggregation (Shaull, 2002). Magnesium also activates or regulates several kinases, ATPases, RUBP carboxylase/oxygenase and many other enzymes of carbohydrate metabolism (Marschner, 1995).

Mg deficiency is likely to decrease the efficiency of the Calvin cycle, reduces the utilization of reductive power (NADPH) and causes an over-saturation of the photosynthetic electron transport system. Enhanced activity of antioxidative enzymes and higher concentrations of antioxidant molecules have been reported in Mg deficient beans (*Phaseolus vulgaris* L.) (Cakmak, 1994), *Mentha* (Candan and Tarhan, 2003) and maize (*Zea mays* L.) plants (Tewari et al., 2004). Furthermore, Mg-deficient leaves can be highly photosensitive and respond to increased light intensity with severe chlorosis and photooxidation of thylakoid constituents, due to generation of reactive oxygen species (Cakmak and Marschner, 1992). At the crop level, this can cause depressed plant growth and yield.

Magnesium deficiency is a major problem, particularly in Italy, where soils have a low plant

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available Mg. This can happen in sandy soils, which have a low pH and cation exchange capacity, and in clays, due to a high K content, which is antagonistic to Mg uptake (Alpi et al., 2000). Moreover, increased use of concentrated mineral fertilisers and decreased use of organic fertilisers have led to a deterioration of soil chemical fertility with lower macro- and microelement availability.

French bean (*Phaseolus vulgaris* L.) is one of the most popular vegetables in Europe. Among other factors such as geographic location, cultivar choice, time of harvest (Martinez et al., 1995), mineral nutrition plays a major role in determining yield and quality of French bean. Foliar fertilisation can give a better rationalisation of plant nutrition. It could be used to correct possible Mg deficiencies, even though a wrong choice of Mg concentration or time of application may have a significant adverse effect on plant growth, yield and quality.

Most studies on the foliar application of nutrients to beans have focused on molybdenum (Mo), boron (B) and zinc (Zn). Increasing molybdenum fertilization to bean from 14 to 100 $g \cdot ha^{-1}$ caused an increase in seed yield by 40%, as a result of favourable effects on structural seed yield components (Coelho et al., 1998; Vieira et al., 1998; Amane et al., 1999). Besides, the above increase in molybdenum fertilization resulted in increases in plant fresh and dry matter (DM), reductases and NO_3 nitrogenase activities and number of root nodules (Vieira et al., 1998).

Boron applied to French bean at an optimal dose of 1 $kg \cdot ha^{-1}$ increased pod length, pod number $plant^{-1}$ and seed yield (Kotur, 1998). Other studies highlighted that foliar applications of phosphorus (P) and B gave earlier flowering and higher pod yield (Singh et al., 1989). Padma et al. (1989) found that combined foliar applications of Mo and B increased plant height, number of leaves, flowers and pods, root length and assimilation area and, above all, increased green pod yield to 4.7 $t \cdot ha^{-1}$, compared to 3 $t \cdot ha^{-1}$ from control plants.

There is a dearth of literature on foliar fertilisation of French bean. A previous work relating to the optimal Mg concentration during early development (Duczmal, 1994) was performed in South America, under very different climatic conditions with respect to Mediterranean areas. Moreover, no research has focused on the combined foliar application of Mg with other nutrients. In particular, Zn fertilisation has given interesting responses in other crops, in terms of higher yield and fruit quality (Barlóg and Grzebisz, 2001); thus, it would seem appropriate to assess whether this latter element may be successfully combined with Mg in foliar applications in French beans.

The above mentioned lack of data was a catalyst to this research, which was designed to study the effect of foliar Mg applications, in several rates and timings, on the yield, biomass and chemical composition of two French bean genotypes; possible effects due to the combined application of Mg with Zn were also considered.

2. Materials and methods

2.1 Crop condition, experimental design and management

The work was conducted in 2004 and 2005 in unheated greenhouses of the Department of Food Science, University of Teramo. The French bean cultivars Bronco (Seminis) and Cadillac (Royal Sluis) were sown on 19 March 2004 and on 24 March 2005 in small pots (5 x 10 x 5 cm) filled with peat:perlite (2:1 volume ratio) and were kept in a propagation greenhouse until seedlings were approximately 8 cm high. Subsequently, seedlings were transplanted on 10 April 2004 and 16 April 2005 onto experimental greenhouse benches, into soil collected from Villarosa (Te) (42° 53' N, 13° 55' E) in October. The soil was not of agricultural origin, because it came from an area covered in native vegetation and had never received any fertiliser, herbicide or pesticide application. It was a sandy-clay loam with the following characteristics: sand 48%, silt 29%, clay 23%, $pH(H_2O)$ 7.2, electrical conductivity (EC) 0.498 mS cm^{-1}, Cation Exchange Capacity 16.67 meq 100 g^{-1}, total $CaCO_3$ 1.2%, total organic matter 1.4%, total N 1.0 g kg^{-1}, P 43 mg kg^{-1}, K 450 mg kg^{-1}, Ca 2300 mg kg^{-1}, Mg 50 mg kg^{-1}, DTPA + TEA + $CaCl_2$ extractable micronutrients (mg kg^{-1}) Fe 20.6, Mn 6.4, Zn 2.6, Cu 8.8, B 0.46, Na 55 (Violante, 2000).

The experimental design was a split-plot arranged as a randomised complete block with three replicates. The two bean genotypes were main-plots, i.e. cv. Bronco, and cv. Cadillac. The first genotype is suitable for fresh consumption while the second is suitable for processing. Eight combinations of Mg dose and time of foliar application were sub-plots: i.e. 56, 112, and 224 g ha^{-1} of Mg at two stages (whole dose applied at approximately onset of flowering or a half the dose at the 4 leaf stage and a half at flowering), plus one treatment with Mg and Zn at 224 + 200 g ha^{-1} (at flowering), plus an unfertilized control. The Mg was applied as the commercial product Brexil Mg (Valagro Spa), while the Zn was applied as Brexil Zn (Valagro Spa).

Subplots were 3 m x 2 m and consisted of 4 rows of French beans at 50 cm apart sown at 30 plants m^{-2} (in-row plant distance of 7 cm). Irrigation was provided via a drip system from 300 L tanks. Plants were irrigated twice a week, aiming at fully restoring field capacity. Irrigation water had the following characteristics: pH 7.55, EC = 0.578 mS cm^{-1}, Mg 0.1 $\mu g \cdot l^{-1}$.

Foliar fertilizer was applied with a plot sprayer fitted with four flat fan nozzles (ALBUZ APG 110 – yellow) delivering 300 L ha^{-1} spray solution at 300 kPa. Before application, a transparent PVC mulch was laid down on the soil between crop rows to prevent nutrient solution from reaching the soil surface and thus avoid fertilizer root uptake. Applications were made on 23 May and 5 June in 2004 and 25 May and 6 June in 2005.

Weeds were controlled by hoeing, at the 2 leaf stage, and, in both years, deltametrine was applied to control aphids at the start of flowering.

2.2 Crop morphology and yield

Final harvest was at 58 days after sowing (DAS) in 2004 and 60 DAS in 2005; total plant biomass was partitioned into aerial biomass, roots and commercial pods, that were weighed separately. Commercial pods $plant^{-1}$ were also counted. Samples from all plant parts were dried in a forced draught oven at 80 °C for 48 h to determine the DM content.

2.3 Chemical quality analysis

Total N level was determined on 3 g samples using the Kjeldahl method.

The ash content of the samples was determined by incineration in a muffle furnace (Gallenkamp hot box) at 550 °C for 24 hours.

For the determination of soluble sugars, nitrate, phosphate, sulphate, magnesium, calcium, potassium content, the apparatus used was an ionic chromatograph Dionex Model ICS 3000 (Dionex corp., Palo Alto, CA, USA). It consists of an anion separator column (Dionex AS14A column (P/N 056904) with a guard column containing the same resin AG14A (P/N 056897), of a cation separator column (Dionex Ion Pac CS12A column (P/N 046073)) with a guard column containing the same resin Ion Pac CG12A (P/N 046074) and a carbohydrates separator column (Dionex Carbo Pac PA1 (P/N 035391)) with a guard column containing the same resin Carbo Pac PA1 (P/N 043096). An anion suppressor (AS) Dionex ASRS ULTRA II 4 mm was also used. The detectors were an heated conductivity cell (P/N 061830) and an electrochemical cell (P/N 061757).

All chemicals were chromatographic grade. The eluents used to determine anion content were 0.05 mM $NaHCO_3$ + 0.05 mM Na_2CO_3. The eluent used to determine cation content was 0.05 mM metansulfonic acid. The eluent used to determine carbohydrate content was 150 mM NaOH, previously treated with Starsonic 90 (Liarre) at 50 Hz for 15 m. Pump pressure was 12411 Nm^{-2} for anions and cations and 9308 Nm^{-2} for carbohydrates.

Calibration curves for the ions and carbohydrates were linear in the concentration range up to 150 ppm. The coefficients of determination (R^2) for glucose, fructose, sucrose nitrate, phosphate, sulphate, magnesium, calcium and potassium were always 0.99. All standard sample materials were purchased from Sigma Aldrich Srl Italia (via Gallarate 154, 20151 Milano).

Sample preparation consisted of collecting 100 g of commercial green pods which were immersed in 500 ml of deionised water and immediately ground to a fine homogenate with an Ultra Turrax T25 basic (IKA-WERKE) for 5 minutes at 13500 rpm. Subsequently a 50 ml aliquot was centrifuged with ALC 4218 (ALC International s.r.l.) for 10 minutes at 3500 rpm and the resulting suspension filtered (Acrodisk syringe filter 0.2 μm). The filtered suspension was diluted with deionised water at a 1:5 ratio and injected into the ionic chromatograph. Loop volume was 25 μl.

2.4 Statistics

Data were subjected to ANOVA separately for each year, to estimate the s.e.d. Differences among treatments were assessed by using t-tests

(P = 0.05) and, wherever appropriate, the quantitative effects of fertilisation was assessed by linear regression analysis. Statistical analyses were performed using Statistical Environment R (R Development Core Team, 2005).

3. Results

3.1 Biomass and yield

Main effects and the genotype x fertilisation interaction were significant (Tab. 1 and 2). On average cv. Bronco produced more biomass than Cadillac (15.6 g DM and 14.3 g DM in 2004, 13.9 g DM and 12.2 g DM in 2005 for cvs. Bronco and Cadillac, respectively). In all cases aerial and root biomass increased with Mg fertilisation rate and, apart from the case of root biomass and cv. Bronco, such increases were linearly related to Mg dose with R^2 values always above 0.80 (regression lines not shown).

In the case of cv. Bronco, biomass increases with Mg dose were much higher with the split Mg application, while adding Zn to the fertilizer solution did not show any significant effect.

In cv. Cadillac, the difference between single and split applications did not show a clear pattern and in several cases it was not significant. When Zn was applied, aerial biomass increased, but root biomass was not affected (Tab. 1).

Pod yield (Tab. 2) increased with Mg doses and such an effect was much higher in cv. Bronco, that showed a higher average yield level (79.7 vs. 43.7 g plant^{-1} in 2004 and 78.7 vs 42.1 g plant^{-1} in 2005) and higher dose related increments (not shown). In both years, the yield of Bronco was higher with split applications. As in the case of aerial and root biomass, the difference between single and split applications in Cadillac was less clear and not always significant (Tab. 2).

In all cases, the addition of Zn did not significantly increase yield.

Table 1. Effect of foliar fertilisation with Mg (% of maximum dose, i.e. 224 g ha^{-1}) on aerial biomass and roots for two French bean varieties in two years.

Variety	Mg rate	N. of appl.	2004				2005			
			Fresh weight (g plant^{-1})		Dry weight (g plant^{-1})		Fresh weight (g plant^{-1})		Dry weight (g plant^{-1})	
			Aerial biomass	Roots	Aerial biomass	Roots	Aerial biomass	Roots	Aerial biomass	Roots
BRONCO	25%	1	48.9	2.6	11.2	0.59	38.8	2.1	9.70	0.47
	50%	1	59.0	2.5	13.9	0.59	46.5	2.0	12.1	0.45
	100%	1	63.1	2.8	16.4	0.66	53.7	2.4	15.3	0.55
	25%	2	62.5	2.7	14.1	0.67	49.4	2.2	12.2	0.55
	50%	2	67.9	2.9	15.8	0.72	58.0	2.4	14.3	0.59
	100%	2	93.4	4.0	23.0	1.01	79.7	3.5	20.9	0.89
	100% + Zn	1	73.4	3.1	18.5	0.77	63.7	2.7	17.0	0.68
	Untreated	-	58.6	2.6	12.0	0.62	47.3	2.1	10.3	0.50
	Overall average	-	*65.9*	*2.9*	*15.6*	*0.70*	54.6	2.4	*13.9*	*0.59*
CADILLAC	25%	1	37.8	2.2	9.9	0.58	26.9	2.0	7.8	0.52
	50%	1	59.4	2.6	15.4	0.70	48.6	2.4	13.4	0.65
	100%	1	63.5	2.9	16.4	0.79	53.0	2.6	14.4	0.72
	25%	2	44.5	3.2	12.3	0.80	32.3	2.8	10.1	0.70
	50%	2	52.6	3.0	13.5	0.77	39.2	2.4	11.2	0.63
	100%	2	64.5	3.9	18.2	1.02	51.3	3.3	15.8	0.88
	100% + Zn	1	81.4	2.6	18.9	0.73	69.7	2.4	16.7	0.65
	Untreated	-	31.9	3.1	10.0	0.78	26.4	2.5	8.5	0.62
	Overall average	-	*54.5*	*2.9*	*14.3*	*0.77*	43.4	2.6	*12.2*	*0.67*
s.e.d.			3.94	0.17	0.64	0.042	4.13	0.20	0.53	0.032
Effect		d.f.								
Cultivar		1	*	n.s.	**	*	*	*	*	**
Fertilisation		7	**	**	**	**	**	**	**	**
C x F		7	**	**	**	**	**	*	**	*

n.s., *, **: not significant or significant at p < 0.05 or p < 0.01.

Table 2. Effect of foliar fertilisation with Mg (% of maximum dose, i.e. 224 g ha^{-1}) on commercial pod fresh weight and numbers per plant for two French bean varieties in two years.

Variety	Mg rate	N. of appl.	Commercial fruit yield (pods)			
			2004		2005	
			g $plant^{-1}$	n $plant^{-1}$	g $plant^{-1}$	n $plant^{-1}$
BRONCO	25%	1	61.1	69	59.6	11
	50%	1	73.3	69	71.2	12
	100%	1	90.6	87	92.6	16
	25%	2	72.1	72	70.9	13
	50%	2	81.8	85	80.2	15
	100%	2	110.9	101	109.6	18
	100% + Zn	1	94.6	88	93.7	16
	Untreated	-	53.5	69	51.7	11
	Overall average	-	*79.7*	*80*	*78.7*	*14*
CADILLAC	25%	1	34.3	82	32.1	14
	50%	1	50.0	103	48.4	18
	100%	1	49.7	97	48.1	17
	25%	2	40.8	85	39.8	14
	50%	2	36.3	83	37.1	14
	100%	2	55.6	113	55.0	19
	100% + Zn	1	43.5	94	41.7	16
	Untreated	-	39.5	77	34.8	14
	Overall average	-	*43.7*	*92*	*42.1*	*16*
s.e.d.			3.81	4.8	4.10	1.0
Effect		d.f.				
Cultivar		1	**	*	**	n.s.
Fertilisation		7	**	**	**	**
C x F		7	**	**	**	**

n.s., *, **: not significant or significant at $p < 0.05$ or $p < 0.01$.

The number of pods per plant followed a trend similar to that of yield (Tab. 2).

3.2 Nitrate and Total Nitrogen content

Notwithstanding a higher biomass and yield, cv. Bronco had a lower average nitrate content in pods (151 vs 265 mg kg^{-1} in 2004 and 144 vs. 258 mg kg^{-1} in 2005) and total N percentage (3.5 vs 4.2 % in 2004 and 2.9 vs. 3.6 in 2005), with respect to Cadillac (Tab. 3).

In cv. Bronco, nitrate accumulation was the highest with the highest Mg doses and the split application was more effective than the single one (Tab. 3). When Zn was added to the nutrient solution, pod nitrate decreased slightly and not significantly, compared to the corresponding single application of Mg alone. Total nitrogen content was also significantly increased with Mg-fertilisation, especially passing from 25 to 50% Mg rate. Zinc significantly increased N content from 3.2% to 4.0%, on average over the two years.

The cv. Cadillac was more responsive to the increase in Mg fertilisation, with respect to Bronco (Tab. 3). The effect was particularly apparent in the case of split applications for nitrate accumulation. Zinc significantly increased nitrate content, but not total nitrogen.

3.3 Sugar content

With regard to pod sugar content, cv. Bronco had a higher average glucose (14.9 vs. 10.4 g kg^{-1} in 2004 and 14.8 vs. 10.3 g kg^{-1} in 2005) and sucrose (0.7 vs 0.4 g kg^{-1} in 2004 and 0.6 vs 0.3 g kg^{-1} in 2005) concentration than Cadillac. Average fructose content was the same in both cultivars at 16.0 g kg^{-1} in both years (Tab. 4).

In cv. Bronco, sugar content increased with Mg dose in all the cases, but the effect was very small (though statistically significant), except in the case of sucrose with split Mg application (Tab. 4), that showed a very high increase (133% and 160% respectively for 2004 and 2005).

Table 3. Effect of foliar fertilisation with Mg (% of maximum dose, i.e. 224 g ha^{-1}) on the content of nitrate and total nitrogen in pods for two French bean varieties in two years.

Variety	Mg rate	N. of appl.	2004 Nitrate (mg Kg^{-1})	2004 TN (%)	2005 Nitrate (mg Kg^{-1})	2005 TN (%)
BRONCO	25%	1	119	2.5	111	1.9
	50%	1	162	3.3	154	2.7
	100%	1	162	3.5	154	2.9
	25%	2	133	3.3	124	2.7
	50%	2	160	3.8	153	3.3
	100%	2	208	3.9	204	3.3
	100% + Zn	1	150	4.3	145	3.7
	Untreated	-	116	3.3	109	2.6
	Overall average	-	*151*	*3.5*	*144*	*2.9*
CADILLAC	25%	1	189	4.4	181	3.8
	50%	1	212	4.6	205	4.0
	100%	1	290	4.0	284	3.4
	25%	2	261	4.3	254	3.7
	50%	2	307	4.1	300	3.5
	100%	2	377	4.5	369	3.9
	100% + Zn	1	330	4.6	322	4.0
	Untreated	-	157	3.4	149	2.8
	Overall average	-	*265*	*4.2*	*258*	*3.6*
s.e.d.			12.0	0.16	11.2	0.18
Effect		d.f.				
Cultivar		1	**	**	**	**
Fertilisation		7	**	**	**	**
C x F		7	**	**	**	**

n.s., *, **: not significant or significant at $p < 0.05$ or $p < 0.01$.

Table 4. Effect of foliar fertilisation with Mg (% of maximum dose, i.e. 224 g ha^{-1}) on the content of glucose, fructose and sucrose in pods for two French bean varieties in two years.

Variety	Mg rate	N. of appl.	2004 Glucose (g Kg^{-1})	2004 Fructose (g Kg^{-1})	2004 Sucrose (g Kg^{-1})	2005 Glucose (g Kg^{-1})	2005 Fructose (g Kg^{-1})	2005 Sucrose (g Kg^{-1})
BRONCO	25%	1	13.8	14.9	0.4	13.5	14.6	0.3
	50%	1	15.0	16.2	0.5	14.7	16.2	0.5
	100%	1	15.7	17.2	0.6	15.5	17.2	0.5
	25%	2	14.4	15.6	0.4	14.2	15.4	0.4
	50%	2	14.6	15.7	0.5	14.3	15.7	0.5
	100%	2	15.3	16.6	1.3	15.6	16.4	1.2
	100% + Zn	1	17.6	18.0	1.4	17.4	18.1	1.3
	Untreated	-	13.3	14.3	0.3	13.0	14.3	0.3
	Overall average	-	*14.9*	*16.1*	*0.7*	*14.8*	*16.0*	*0.6*
CADILLAC	25%	1	8.4	12.9	0.2	8.4	12.5	0.2
	50%	1	9.2	15.4	0.3	9.0	15.3	0.3
	100%	1	10.8	16.9	0.4	10.8	17.3	0.3
	25%	2	11.1	16.3	0.3	11.0	16.2	0.3
	50%	2	10.9	16.6	0.3	11.0	16.5	0.3
	100%	2	12.2	18.4	0.5	11.8	18.5	0.5
	100% + Zn	1	12.3	18.8	0.7	11.8	18.8	0.6
	Untreated	-	8.4	12.7	0.2	8.3	12.6	0.2
	Overall average	-	*10.4*	*16.0*	*0.4*	*10.3*	*16.0*	*0.3*
s.e.d.			0.35	0.36	0.08	0.43	0.37	0.10
Effect		d.f.						
Cultivar		1	**	n.s.	*	**	n.s.	*
Fertilisation		7	**	**	**	**	**	**
C x F		7	**	**	**	**	**	**

n.s., *, **: not significant or significant at $p < 0.05$ or $p < 0.01$.

Table 5. Effect of foliar fertilisation with Mg (% of maximum dose, i.e. 224 g ha^{-1}) on the content of ash, phosphate and sulphate for two French bean varieties in two years.

Variety	Mg rate	N. of appl.	2004 Ash (%)	2004 P (mg Kg^{-1})	2004 S (mg Kg^{-1})	2005 Ash (%)	2005 P (mg Kg^{-1})	2005 S (mg Kg^{-1})
BRONCO	25%	1	4.39	2146	102	4.31	1716	76
	50%	1	4.54	2500	112	4.59	2503	87
	100%	1	4.89	2917	109	4.83	2866	83
	25%	2	5.17	2207	98	5.11	2228	71
	50%	2	5.34	2674	99	5.39	2608	74
	100%	2	5.58	2859	111	5.52	2873	86
	100% + Zn	1	5.55	3469	112	5.53	3522	87
	Untreated	-	4.43	2372	72	4.32	2473	50
	Overall average	-	*4.99*	*2643*	*102*	*4.95*	*2599*	*77*
CADILLAC	25%	1	4.70	4103	118	4.61	3988	94
	50%	1	4.79	4343	120	4.72	4229	94
	100%	1	5.15	3964	132	5.19	3687	109
	25%	2	5.55	3424	125	5.57	3436	97
	50%	2	5.63	3764	141	5.60	3743	114
	100%	2	5.81	3765	152	5.72	3777	121
	100% + Zn	1	5.86	4067	135	5.83	3996	110
	Untreated	-	4.63	3243	127	4.69	3204	98
	Overall average	-	*5.27*	3834	131	*5.24*	3758	105
s.e.d.			0.097	100.0	3.9	*0.101*	*220.8*	*3.5*
Effect		d.f.						
Cultivar		1	**	**	**	**	**	**
Fertilisation		7	**	**	**	**	**	**
C x F		7	n.s.	**	**	n.s.	**	**

n.s., *, **: not significant or significant at $p < 0.05$ or $p < 0.01$.

Effects were similar in cv. Cadillac, but the effect of split Mg application on sucrose content was not as marked as in cv. Bronco. Similarly, Zn increased sucrose level (by 40% in 2004 and 100% in 2005), but less than in cv. Bronco.

3.4 Ash and ion content

In terms of ash content, the interaction fertilisation x variety was not significant and both varieties responded to Mg with a slight linear dose-dependent increase (regression lines are not shown, see data in Tab. 5). The effect of Zn was positive and significant in both cultivars and the ash content increased by 25.2% in cv. Bronco and 26.6% in cv. Cadillac, on average in the two years.

In cv. Bronco there was a significant increase in phosphate and sulphate contents with Mg dose, particularly passing from 25 to 50% Mg rate. Otherwise, differences between single and split applications were not significant (Tab. 5). Addition of Zn to the fertiliser mix significantly enhanced phosphate but not sulphate content.

Cadillac had a higher average phosphate and sulphate content than Bronco (3834 vs 2643 mg P Kg^{-1} in 2004; 3758 vs. 2599 mg P Kg^{-1} in 2005; 131 vs 102 mg S Kg^{-1} in 2004 and 105 vs 77 mg S Kg^{-1} in 2005), even though the response to increased Mg dose was similar to that of Bronco (Tab. 5). The addition of Zn to the fertiliser mix did not give any significant effect.

With respect to cation macronutrient, in both varieties Mg fertilization increased Ca and Mg content (this was significant only in 2004) and decreased K content (Tab. 6). Cv. Cadillac had a higher average content in all cations with respect to cv. Bronco.

The effect of split applications was significant only in the case of cv. Cadillac, with reference to Mg and Ca accumulation.

4. Discussion

The beneficial effect of foliar application of Mg on French bean plants was evident in total biomass accumulation and yield. It also affected plant structure, both bean cultivars responded

Table 6. Effect of foliar fertilisation with Mg (% of maximum dose, i.e. 224 g ha^{-1}) on the content of magnesium, calcium and potassium for two French bean varieties in two years.

Variety	Mg rate	N. of appl.	2004 Mg (mg Kg^{-1})	2004 Ca (mg Kg^{-1})	2004 K (mg Kg^{-1})	2005 Mg (mg Kg^{-1})	2005 Ca (mg Kg^{-1})	2005 K (mg Kg^{-1})
BRONCO	25%	1	119	90	1949	101	74	2130
	50%	1	124	103	2928	123	81	3140
	100%	1	150	132	2875	146	116	2938
	25%	2	123	88	2375	104	67	2496
	50%	2	137	104	2659	128	85	2845
	100%	2	192	160	3614	177	139	3740
	100% + Zn	1	208	174	3625	197	159	3753
	Untreated	-	184	86	3225	176	154	3479
	Overall average	-	*155*	*117*	*2906*	*144*	*109*	*3065*
CADILLAC	25%	1	249	243	3769	244	228	4105
	50%	1	221	198	3622	214	186	3722
	100%	1	208	195	3421	193	171	3402
	25%	2	250	257	4270	228	232	4407
	50%	2	249	223	4050	242	218	4061
	100%	2	312	285	4421	303	276	4568
	100% + Zn	1	226	197	4355	210	182	4334
	Untreated	-	219	152	3964	252	228	4736
	Overall average	-	*242*	*219*	*3984*	*236*	*215*	*4167*
s.e.d.			15.6	18.9	112.7	36.6	37.1	197.3
Effect		d.f.						
Cultivar		1	**	**	**	**	**	*
Fertilisation		7	**	**	**	n.s.	n.s.	**
C x F		7	**	**	**	n.s.	n.s.	**

n.s., *, **: not significant or significant at $p < 0.05$ or $p < 0.01$.

to foliar fertilisation with increased above ground biomass, and higher number and weight of commercial pods. This confirms findings by Pszczółkowska et al. (2003) who observed that Mg fertilisation in white lupin (*Lupinus albus* L.) significantly increased seed weight per plant, number of seeds per pod and induced first pod set at a lower node. Reinbott and Blevins (1995) reported that 4 foliar applications of a combination of B and Mg increased soybean (*Glycine max* (L.) Merr.) yield by 12% and 4% at two locations over 3 years. These effects can be explained by faster CO_2 fixation, due to increased CO_2 uptake and RUBP-carboxylase activity (Seftor et al., 1986). Fischer et al. (1998) as well as Fischer and Bremer (1993) suggested that Mg plays a role in source-sink relationships, favouring assimilate translocation towards sinks.

The positive effect of Zn on plant and root biomass, not coupled with a similar effect on yield, matches the findings of Cakmak and Marschener (1986, 1990) who noted that wheat (*Triticum aestivum* L.) and cotton (*Gossypium hirsutum* L.) DM increased as Zn concentration was increased from a deficit to a sufficient level. Kaya and Higgs (2002) also found that foliar Zn applications at 0.35 mmol l^{-1} enhanced DM production in two tomato (*Lycopersicon esculentum* Mill.) cultivars, but did not affect yield.

When the Mg fertiliser was applied in a split application, the two varieties responded differently in yield and biomass production. This could be explained from their different growth. Bronco has late flowering and fruit set, and a long ripening phase. Cadillac is an earlier variety and it may have not been able to effectively utilize the nutrients applied during flowering.

Concerning nitrogen and nitrate content in pods, the observed values were similar to those determined for French beans by Khah and Arvanitoyannis (2003) and Kirk and Sawyer (1991).

Carbohydrate analyses showed that cv. Bronco contained higher average fruit sugar levels confirming its better suitability for processing. The increase in sucrose, fructose and glucose content after Mg fertilisation in both varieties, although very slight, may be explained by increased phloem loading and photosynthate translocation towards sinks (Cakmak et al., 1994) or by increased sink growth and thus decreased sink-limitation (Fischer and Bremer, 1993; Alaoui-Sossé et al., 2004).

With regard to ions content, the effect of Mg fertilisation on the concentration of Mg in pods was partly expected even tough an increase was only evident at high fertilizer doses. It should be noted that Mg at low rates was antagonistic to K content, as reported in other legumes (Narwal et al., 1985).

Concerning anions, pod phosphate content was increased by Mg fertilisation, especially with a split application at the highest dose. This confirms results obtained in cucumber (*Cucumis sativus* L.), tomato, lettuce (*Lactuca sativa* L.) (Jarvan and Poldma, 2004) and broccoli (*Brassica oleracea* L.) (Demchak and Smith, 1990).

5. Conclusions

Mg fertilisation of French beans increased yield and quality, with particular reference to pod sucrose, fructose, and glucose as well as nitrate, phosphate, sulphate magnesium and calcium content, that may be of relevance to human health and nutrition. However, particular care should be taken of the nitrate content, which in some cases was increased by Mg-fertilisation, especially in cv. Bronco. Even though the effect was low and the nitrate content was always below the limits of current regulations, this should be considered when planning field applications of Mg, with reference to the varietal choice and fertiliser rate.

From a grower's perspective, split application of Mg fertilisers at two growth stages (fourth leaf and at flowering) seems advisable to maximise fertiliser efficiency, with no risk of foliar damage, particularly in the case of varieties characterised by a long ripening phase.

The addition of Zn to the fertiliser mix, on the other hand, does not seem advisable, as it did not give any effects of practical relevance.

References

Alaoui-Sossé B., Genet P., Vinit-Dunand F., Toussaint M.L., Epron D., Badot P.M. 2004. Effect of copper on growth in cucumber plants (*Cucumis sativus* L.) and its relationships with carbohydrate accumulation and changes in ion contents. Plant Science, 166:1213-1218.

Alpi A., Pupillo P., Rigano C. 2000. Nutrizione nella pianta. In: . Alpi A., Pupillo P. Rigano C. (eds.): Fisiologia delle Piante. Edpublishing EdiSES, Naples.

Amane M.I.V., Vieira C., Novais R.F., Araujo G.A. 1999. Nitrogen and molybdenum fertilization of the common bean crop in the "Zona da Mata" region, Minas Gerais. Revista Brasileira de Ciencia do Solo, 23:643-650.

Barlóg P., Grzebisz W. 2001. Effect of magnesium foliar application on the yield and quality of sugar beet roots. Rostlinná Vỳroba, 47, 9:418-422.

Cakmak I., Hengeler C., Marschner H. 1994. Changes in phloem export of sucrose in leaves in response to phosphorus, potassium and magnesium deficiency in bean plants. Journal of Experimental Botany, 45:1251-1257.

Cakmak I., Marschner H. 1990. Decrease in nitrate uptake and increase in proton release in zinc-deficient cotton, sunflower and buckwheat plants. Plant and Soil, 129:261-268.

Cakmak I., Marschner H. 1992. Magnesium deficiency and high light intensity enhance activities of superoxide dismutase, ascorbate peroxidase and glutathione reductase in bean leaves. Plant Physiology, 98:1222-1227.

Cakmak I., Marschner H. 1986. Mechanism of phosphorus-induced zinc deficiency in cotton: I. Zinc-deficiency-enhanced uptake rate of phosphorus. Physiology Plantarum, 68:483-490.

Cakmak I. 1994. Activity of ascorbate-dependent H_2O_2-scavenging enzymes and leaf chlorosis are enhanced magnesium and potassium-deficient leaves, but not in phosphorus-deficient leaves. Journal of Experimental Botany, 45:1259-1266.

Cakmak I., Hengeler C., Marschner H. 1994. Partitioning of shoot and root dry matter and carbohydrates in bean plants suffering from phosphorus, potassium and magnesium deficiency. Journal of Experimental Botany, 45:1245-1250.

Candan N., Tarhan L. 2003. Relationship among chlorophyll-carotenoid content, antioxidant enzyme activities and lipid peroxidation levels by Mg^{2+} deficiency in the *Mentha pulegium* leaves. Plant Physiology and Biochemistry, 41:35-40.

Coelho F.C., Vieira C., Mosquim P.R., Cassini S.T.A. 1998. Nitrogen and molybdenum for sole-cropped and intercropped maize and beans. I. Effects on beans. Revista Ceres., 45:393-407.

Demchak K.T., Smith C.B 1990. Yield responses and nutrient uptake of broccoli as affected by lime type and fertilizer. Journal of the American Society of Horticultural Science, 115:737-740.

Duczmal K. 1994. Strączkowe rośliny białkowe. Fasola. Dorobek polskiej hodowli i nasiennictwa fasoli. (Legumes. Bean. Output of Polish bean breeding and seed production.). Mat. konf. 12-19 (in Polish).

Fischer E.S., Bremer E.1993. Influence of magnesium deficiency on rates of leaf expansion, and net photosynthesis in *Phaseolus vulgaris*. Physiologia Plantarum, 89:271-276.

Fischer E.S., Lohaus D., Heineke D., Heldt W. 1998. Magnesium deficiency results in accumulation of carbohydrates and amino acids in source and sink leaves of spinach. Physiologia Plantarum, 102:16-20.

Jarvan M., Poldma P. 2004. Content of plant nutrients in vegetables depending on various lime materials used for neutralising bog peat. Agronomy Research, 2:39-48.

Kaya C., Higgs D. 2002. Response of tomato (*Lycopersicon esculentum* L.) cultivars to foliar application of zinc when grown in sand culture at low zinc. Scientia Horticulturae, 93:53-64.

Khah, E.M., Arvanitoyannis I.S. 2003. Yield, nutrient content and physico-chemical and organoleptic properties in green bean are affected by N:K ratios. Food, Agriculture & Environment 1, 3-4:17-26.

Kirk R.S., Sawyer R. 1991. Pearson's composition and analysis of foods, publishing Harlow, Longman Scientific and Technical.

Kotur S.C. 1998. Evaluation of lime, boron and their residue on three cropping sequences of non-cruciferous vegetables for yield, composition of leaf and soil properties on an Alfisol. Indian Journal of Agricultural Science, 68:718-721.

Marschner H. 1995. Mineral Nutrition of Higher Plants, second ed. London, Academic Press.

Martinez C., Ros G., Periago M.J., Lopez G., Ortuno J., Rincon F. 1995. Physico-chemical and sensory quality criteria of green beans (*Phaseolus vulgaris,* L.). Lebensm. Wiss. U. Technology, 28:515-520.

Narwal R.P., Vinod K., Singh J. 1995. Potassium and magnesium relationship in cowpea (*Vigna unguiculata* (L.) Walp.). Plant and Soil, 86:129-134.

Padma M., Reddy S.A., Babu R.S. 1998. Effect of foliar sprays of molybdenum (Mo) and boron (B) on vegetative growth and dry matter production of French bean (*Phaseolus vulgaris* L.). Journal of Research Andhra Pradesh Agriculture University, 17:87-89.

Pszczółkowska A., Olszewski J., Płodzień K., Kulik T., Fordoński G., Żuk-Gołaszewska K. 2003. Effect of the water stress on the productivity of selected genotypes of pea (*Pisum sativum* L.) and yellow lupin (*Lupinus luteus* L.). Electronic Journal of Polish Agricultural Universities, 6:1-7.

R Development Core Team 2005. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, http://www.r-project.org.

Reinbott T.M., Blevins D.G. 1995. Response of soybean to foliar-applied boron and magnesium and soil-applied boron. Journal of Plant Nutrition, 18:179-200.

Seftor R.E.B., Bahr J.T., Jensen R.G. 1986. Measurement of the enzyme-CO_2-Mg^{2+} form of spinach ribulose 1,5-bisphosphate carboxylase/oxygenase. Plant Physiology, 80:599-600.

Shaul O. 2002. Magnesium transport and function in plants: the tip of the iceberg. BioMetals, 15:309-323.

Singh B.P., Singh B., Singh B.N. 1989. Influence of phosphorus and boron on picking behaviour and quality of French bean (*Phaseolus vulgaris* L.), under limited irrigation, grown in Alfisol deficient in P and B. Indian Journal of Agricultural Science, 59:541-543.

Tewari R.K., Kumar P., Tewari N., Srivastava S., Sharma P.N. 2004. Macronutrient deficiencies and differential antioxidant responses-influence on the activity and expression of superoxide dismutase in maize. Plant Science, 166:687-694.

Vieira R.F., Cardoso E.J.B.N., Vieira C., Cassini S.T.A. 1998. Foliar application of molybdenum in common bean. III. Effect on nodulation. Journal of Plant Nutrition, 21:2153-2161.

Vieira R.F., Vieira C., Cardoso E.J.B.N. Mosquim P.R. 1998. Foliar application of molybdenum in common bean. II. Nitrogenase and nitrate reductase activities in a soil of low fertility. Journal of Plant Nutrition, 21:2141-2151.

Violante P. 2000. Metodi di analisi chimica del suolo. Rome, Ed. Franco Angeli.