Previous legumes and N fertilizer effects on mineral concentration and uptake by forage corn

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Paré, T., Chalifour, F.-P., Bourassa, J. and Antoun, H. 1993. **Previous legumes and N fertilizer effects on mineral concentration and uptake by forage corn.** Can. J. Plant Sci. **73**: 461–476. The beneficial effects of legumes grown in rotation with cereal crops can, in part, be attributed to soil N increments through the fixation of atmospheric N_2 and conservation of soil N. Other rotation effects have been suspected, but have not all been characterized. The objectives of the present study were to determine the impact of faba bean (*Vicia faba* L.) and soybean (*Glycine max* [L.] Merr.) on the mineral composition and uptake of a subsequent forage-corn (*Zea mays* L.) crop. Field experiments were conducted in 1987 and 1988 on a Rivière-du-Loup gravelly sandy loam (Ferro Humic Podzol) at St-Anselme and on a Chaloupe silty loam (Orthic Humic Gleysol) at Deschambault in eastern Quebec. In continuous cropping or following soybean Maple Amber or faba bean Outlook, N rates applied to corn Pioneer 3979 were 0, 50, 100 or 150 kg N ha^{-1}. In 1987, generally, the corn mineral composition and uptake were not significantly affected by N treatments. Soil mineral concentrations were measured in spring 1988 at both sites, but only a few differences were observed among treatments. In 1988, at St-Anselme, the K concentration of stover and whole plants increased following legumes at all N levels applied, but decreased at Deschambault as the N level increased up to 100 kg N ha^{-1} for all previous crops. At St-Anselme, the Ca uptake of the corn stover following faba bean was higher than that following corn. At the same location, the K uptake by stover was higher following legumes than following corn. The Mg uptake by subsequent corn at St-Anselme was higher following faba bean than following corn and soybean, while at Deschambault, it generally increased with N application following all previous crops. At both sites, the stover and the whole-plant P uptake varied with N application that also affected Fe and Mn concentrations and uptake.

Key words: Forage corn, faba bean, soybean, N fertilizer, mineral concentration and uptake

Paré, T., Chalifour, F.-P., Bourassa, J. et Antoun, H. 1993. **Effets des précédents légumineuses et de la fertilisation azotée sur l'absorption et la concentration minérales du maïs fourrage.** Can. J. Plant Sci. **73**: 461–476. Les effets bénéfiques des légumineuses cultivées en rotation avec des céréales peuvent être en partie attribués à l'augmentation des teneurs en N du sol grâce à la fixation d'azote (N_2) atmosphérique et à la conservation de l'azote du sol. D'autres effets de rotation ont été proposés mais n'ont pas été tous caractérisés. Les objectifs de la présente étude étaient de déterminer l'impact de la féverole (*Vicia faba* L.) et du soja (*Glycine max* [L.] Merr.) sur l'absorption et la composition minérales du maïs-fourrage (*Zea mays* L.). Des expériences au champ se sont déroulées en 1987 et 1988 sur un loam sablo-graveleux de la série Rivière-du-Loup (podzol ferro-humique) à St-Anselme et un loam argileux de la série Chaloupe (gleysol humique orthique) à Deschambault dans l'est du Québec. En monoculture, ou suivant le soja Maple Amber ou la féverole Outlook, 0, 50, 100 ou 150 kg d'N ha^{-1} ont été appliqués au maïs Pioneer 3979. En 1987, en général, la fertilisation azotée n'a pas influencé la composition chimique ni l'absorption des éléments minéraux par le maïs. Les analyses minérales des sols ont été effectuées au printemps 1988, mais seules de légères différences ont été observées entre les traitements. En 1988, à St-Anselme, les concentrations en K des cannes et des plantes entières de maïs ont augmenté subséquemment aux légumineuses, quelle que soit la dose

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d'N appliquée, mais ont diminué à Deschambault avec l'application de la dose de 100 kg N ha^{-1} quel que soit le précédent cultural. À St-Anselme, l'absorption de Ca par les cannes de maïs subséquent à la féverole était supérieure à celles suivant le maïs et le soja. Au même site, les cannes ont absorbé plus de K après les légumineuses qu'en monoculture. L'absorption de Mg par le maïs suivant la féverole était supérieure à celle par le maïs subséquent au soja et en monoculture à St-Anselme, alors qu'à Deschambault, elle a généralement augmenté avec l'application d'N quel que soit le précédent cultural. Aux deux sites, l'absorption de P par les cannes et les plantes entières a varié avec l'application d'N qui a également influencé les concentrations et l'absorption de Fe et de Mn.

Mots clés: Maïs-fourrage, féverole, soja, fertilisants azotés, concentration et absorption minérales

While the effects of legumes as previous crops on the growth and yield of a subsequent corn production are well described (Hesterman et al. 1986; Bruulsema and Christie 1987; Paré et al. 1992), little is known about their effects as possible enhancers of nutrient uptake by a subsequent corn crop. Hoyt (1987) reported that legume cover crops, in addition to the fixation of substantial atmospheric dinitrogen (N_2), can recycle other plant-essential nutrients. Studying the effects of crimson clover (*Trifolium incarnatum* L.) on the P and cations cycling in a humid subtropical agroecosystem, Groffman et al. (1987) found that these mineral concentrations in subsequent sorghum (*Sorghum bicolor* (L.) Moench) tended to be higher following clover than rye (*Secale cereale* L.). To explain these favorable effects, several hypotheses can be put forward. Legumes as previous crops may take up less nutrients, making them more available for the subsequent crop. The N_2 fixed and then released from the legume residues through mineralization and the soil N not used by the previous legume promote the growth of corn; its root system becomes more important, allowing a better contact with a greater soil volume and a better exploration for nutrients. Finally, during the decomposition of legume residues, chemical elements other than N could be released into the soil and used by the subsequent crops. Therefore, the return of crop residues to the soil is a prime source of these nutrients that can be recycled through the ecosystem (Power and Legg 1978). It has been shown that a good part of these elements, particularly P and K, contained in plant residues, is released by the mechanical disruption of the plant cells after freezing or drying (Allison 1973; Martin and Cunningham 1973) in opposition to N for which the soil microfloral activity is the prime agent causing nutrients to flow out of residues (Power and Legg 1978). It has been also reported that N fertilization appears to increase the concentrations of P and K, and possibly, of other ions, if their level of availability in the soil is high (Gashaw and Mugwira 1981; Ebelhar et al. 1987); however, if the soil supply is low, their concentrations in the plant may be reduced (Hunt 1974).

Paré et al. (1992) found that in eastern Quebec, faba bean as previous crop contributed to a partial and to a total reduction of the fertilizer N needs of subsequent forage corn, at Deschambault and St-Anselme, respectively, while soybean did not contribute to the N nutrition of subsequent corn. On the other hand, the contribution of these two legumes, on the uptake of nutrients other than N by subsequent corn are unknown. The objective of this study was to determine the effects of faba bean and soybean as previous crops, and their interaction with N application on the mineral concentration and uptake by a subsequent forage corn crop.

MATERIALS AND METHODS

Field experiments were conducted in 1987 and 1988 growing seasons on a Rivière-du-Loup gravelly sandy loam (Ferro-Humic Podzol) at St-Anselme and on a Chaloupe silty loam (Orthic Humic Gleysol) at Deschambault in eastern Quebec. Some properties of the soils, cultural practices, meteorological data and experimental design were described in detail by Paré et al. (1992), in which the dry-matter yields and N uptake were reported for this same experiment. In brief, crop sequences were corn Pioneer 3979 grown in monoculture (1987 and 1988), or 1 yr of corn (1988) preceded by 1 yr of either faba bean Outlook or soybean Maple Amber. Corn ears and stover and legume grains were harvested in 1987 and legume residues were incorporated. In monoculture or following legumes, corn was fertilized, (banding 15 cm apart the row) with 0, 50, 100 or 150 kg N ha^{-1} as described by Paré et al. (1992).

After harvesting, in both years, the corn tissue mineral concentrations were determined using ground plant material passed through a 32-mesh sieve. The Cu, Zn, Fe and Mn concentrations were determined by atomic absorption spectrophotometry (Gaines and Mitchell 1979) after oxidation with HNO_3 and $HClO_4$. Determinations of Ca and Mg were done by atomic absorption spectrophotometry, after dilution of the HNO_3 and $HClO_4$ oxidized products with La_2O_3 (Gaines and Mitchell 1979). Potassium was analyzed as recommended by the Association of Agricultural Chemists (1975) after extraction with $(NH_4)_2C_2O_4 \cdot H_2O$. Phosphorus was determined with the vanado-molybdate method (Varley 1966) on a Technicon Auto Analyzer (Technicon Industrial System, Tarrytown, NY). The uptake of each mineral by the different fractions (i.e., stover and ears), and by the whole plants was estimated by multiplying the concentration of each mineral by the corresponding DMY (Paré et al. 1992). Faba bean and soybean seeds and residues were also analysed for their total mineral concentrations using the same methods cited above for corn.

Soil from plots was sampled from the 0- to 15-cm layer in spring 1988 at both locations and analysed for cations and micronutrients availability, after extraction with Mehlich III method (Mehlich 1984) and the minerals determined as for legume materials.

Statistical analyses were carried out using the procedure GLM in SAS (Statistical Analysis System Institute, Inc. 1985). For each variable, experimental error variances for each site were tested for homogeneity using Bartlett's test (Gomez and Gomez 1984). Combined analyses of variance across sites were performed and are reported since the error variances were homogeneous, except for soil mineral concentrations for which sites were analysed separately. The orthogonal contrasts were calculated for first-year corn, and for second-year corn following different first-year crops, to determine significant linear or quadratic trends in corn N response. Regression equations determining the N response of corn were calculated on the basis of orthogonal trend comparisons for Ca, K and Mg uptakes. The summary of analyses of variances for forage-corn minerals (Ca, Mg and K) for which there are significant effects of previous crops and N application are presented; for the others (P, Cu, Zn, Fe and Mn), when previous crops, N application or their interactions are significant, the probability levels are specified in brackets in the text.

RESULTS

Corn Mineral Concentrations and Uptake in 1987

In general, nitrogen application did not significantly affect the mineral concentrations of corn at both locations, except for the stover Mg and Mn, the ear K and Cu, and the whole-plant Mn concentrations which increased proportionally to N levels (data not shown). The stover Mg and Mn, and the whole-plant Mn concentrations increased linearly with N application at both locations, while the uptake of the other minerals measured (Ca, K, P, Cu, Zn, Fe) was not influenced by N (data not shown).

Soil Mineral Concentrations in Spring 1988

The levels of extractable nutrients in soil in spring 1988 did not show differences among treatments (Table 1). However, there were exceptions at St-Anselme with higher levels of Mg and Cu following soybean than corn, but a lower level of Mg following faba bean than corn (Table 1). At Deschambault, the soil Mg concentration was higher following soybean than corn while that of Fe showed an inverse tendency; at the same location, following faba bean, the soil K concentration was higher than following corn (Table 1).

Corn Mineral Concentrations in 1988

There were significant effects of previous crops on the mineral concentrations of subsequent corn (Tables 2, 3 and 4). At St-Anselme, the stover and whole-plant Ca concentrations were higher for corn preceded by faba bean or soybean than for continuous corn, while at Deschambault, the stover and

Table 1. Soil mineral composition at St-Anselme and Deschambault following corn, soybean and faba bean in spring 1988

Previous crops (1987)		St-Anselme								Deschambault							
		P^z	Ca	Mg	K	Zn^y	Cu^y	Mn	Fe	P	Ca	Mg	K	Zn^y	Cu^y	Mn	Fe
		(g kg^{-1})				(mg kg^{-1})				(g kg^{-1})				(mg kg^{-1})			
Corn		0.10	1.9	0.09	0.10	8.23	7.22	186	289	0.03	3.3	0.22	0.11	11.99	8.66	47.5	353
Soybean		0.10	2.6	0.10	0.09	9.30	10.76	193	282	0.04	4.3	0.37	0.13	10.21	10.37	59.0	312
Faba bean		0.08	2.9	0.08	0.09	8.28	7.76	207	255	0.04	3.0	0.20	0.15	15.60	9.04	44.6	357
							Summary of analyses of variance										
Source of variation	df	P	Ca	Mg	K	Zn	Cu	Mn	Fe	P	Ca	Mg	K	Zn	Cu	Mn	Fe
							Mean squares										
Rep^x	3	2.07	660	0.5	2.50	0.02	0.12	4812	1008	0.2	299	2.66	2.29	0.06	0.07	186	1291
PC^w	2	0.83	1098	0.3***	0.07	0.02	0.18	464	1296	0.02	1857	5.4	1.74	0.18	0.03	225	2445
C^v vs. S^u	1	0.002	982	0.2***	0.10	0.03	0.32*	117	91	0.03	2100	5.2**	0.74	0.05	0.06	255	3240**
C vs. F^t	1	1.19	2100	0.08**	0.12	0.00	0.01	905	2312	0.04	141	0.8	3.48*	0.14	0.003	16.79	45
Error	6	2.41	671	0.004	1.41	0.05	0.04	2522	1357	0.05	410	0.2	0.30	0.09	0.03	110	173

[z] Means of four replications.
[y] Means of ln-transformed data transformed back to original scale.
[x] Replications.
[w] Previous crops.
[v] Corn.
[u] Soybean.
[t] Faba bean.
*,**,***Significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

Table 2. Summary from the analyses of variance for second-year corn cations concentration (g kg^{-1} × 100) at St-Anselme and Deschambault in 1988

Source of variation	df	Stover			Ears			Whole plants		
		Ca	Mg	K	Ca	Mg	K	Ca	Mg	K
		(Mean squares)								
Location (L)	1	(20.0)	(4.0)	(763.1)	(0.4)	(1.5)	(29.0)	(3.4)	(2.4)	(217.5)
Rep[z] (within) L	6	1.1	0.2	62.3	0.5	0.3	1.4	0.2	0.2	12.0
PC[y]	2	0.2	2.0***	49.7*	0.05	0.2	8.1***	0.4	0.1	29.8**
C[x] vs. S[w]	1	0.3*	3.4***	0.6*	0.08	0.2	15.0***	0.6	0.3	42.0**
C vs. F[v]	1	0.0	1.9**	0.9**	0.002	0.3	8.5**	0.01	0.03	47.3**
Nitrogen (N)	3	0.3	0.7*	28.6	0.08	0.2	4.0*	0.1	0.16	18.6**
N_L[u]	1	0.3	1.8**	29.4	0.08	0.1	8.3**	0.02	0.5*	29.9**
N_Q[t]	1	0.4	0.4	53.0*	0.04	0.5*	2.4	0.2	0.005	16.2*
N × PC	6	0.5	0.2	14.0	0.06	0.05	1.2	0.1	0.07	2.7
N_L × (C vs. S)	1	0.8	0.2	7.0	0.003	0.1	0.23	0.2	0.2	4.8
N_L × (C vs. F)	1	0.07	0.2	0.02	0.03	0.2	0.4	0.08	0.001	0.03
N_Q × (C vs. S)	1	0.3	0.6	0.4	0.2	0.05	2.3	0.1	0.06	0.1
N_Q × (C vs. F)	1	1.7	0.01	15.3	0.2	0.04	4.8	0.5	0.1	2.0
L × PC	2	6.2***	0.0	0.1	0.0	0.4*	0.5	2.3***	0.02	0.5
L × (C vs. S)	1	8.5**	0.0	0.1	0.0	0.8**	0.8	2.9***	0.03	0.7
L × (C vs. F)	1	10.2***	0.0	0.2	0.0	0.5*	0.02	3.9***	0.04	9.0
L × N	3	0.03	0.1	3.0	0.15	0.01	0.4	0.1	0.04	0.7
L × PC × N	6	0.5	0.3	7.4	0.05	0.09	1.1	0.26	0.02	0.07
Error	66	0.8	0.2	11.0	0.08	0.9	1.0	0.2	0.07	4.0
Total	95									

[z] Replications.
[y] Previous crops.
[x] Corn.
[w] Soybean.
[v] Faba bean.
[u] Linear effect of N.
[t] Quadratic effect of N.
*,**,***Significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

Table 3. Ca, Mg, K and P concentrations of the stover, ears and whole plants of second-year corn grown in monoculture or following soybean or faba bean, and fertilized with N at St-Anselme in 1988

First-year treatment (1987)	Second-year treatment (1988)	Stover				Ears				Whole plants			
		Ca	Mg	K	P	Ca	Mg	K	P	Ca	Mg	K	P
		($g\ kg^{-1}$)											
Corn 0 N	Corn 0 N[z]	3.0[y]	1.4	17.6	1.4	0.5	1.1	10.1	3.8	1.6	1.2	13.4	2.7
50 N	50 N	2.9	1.5	17.5	1.2	0.5	1.1	9.6	4.3	1.5	1.3	13.0	2.9
100 N	100 N	3.0	1.6	16.4	1.0	0.5	1.1	9.3	3.2	1.5	1.3	12.2	2.3
150 N	150 N	3.1	1.6	16.9	1.1	0.5	1.2	9.7	3.8	1.7	1.3	12.6	3.1
Soybean 20 N	Corn 0 N	3.2	1.4	18.6	1.7	0.5	1.2	10.0	4.4	1.6	1.2	13.7	3.3
	50 N	3.2	1.5	17.0	1.1	0.5	1.0	10.1	3.4	1.7	1.2	13.1	2.4
	100 N	3.0	1.4	18.0	1.0	0.5	1.0	9.6	3.1	1.6	1.2	13.1	2.2
	150 N	3.0	1.5	18.4	1.6	0.5	1.1	10.0	3.5	1.6	1.3	13.6	2.7
Faba bean 20 N	Corn 0 N	3.3	1.4	18.0	1.2	0.6	1.1	10.0	3.2	1.7	1.2	13.5	2.3
	50 N	3.2	1.4	19.0	1.3	0.5	1.1	9.9	2.5	1.7	1.3	13.5	2.0
	100 N	3.2	1.5	18.0	1.5	0.5	1.1	10.0	3.0	1.7	1.3	13.6	2.3
	150 N	3.2	1.5	17.9	1.6	0.6	1.1	9.7	3.4	1.8	1.3	13.4	2.6
Standard error		0.1	0.1	0.7	0.15	0.05	0.04	0.2	0.4	0.04	0.05	0.04	0.4

[z] Nitrogen ($kg\ ha^{-1}$) as NH_4NO_3.
[y] Means of four replications.

Table 4. Ca, Mg, K and P concentrations of the stover, ears and whole plants of second-year corn grown in monoculture or following soybean or faba bean, and fertilized with N at Deschambault in 1988

First-year treatment (1987)	Second-year treatment (1988)	Stover				Ears				Whole plants			
		Ca	Mg	K	P	Ca	Mg	K	P	Ca	Mg	K	P
		(g kg^{-1})											
Corn 0 N	Corn 0 N[z]	3.1[y]	1.4	19.9	1.5	0.4	0.9	10.0	2.2	1.7	1.1	14.3	1.8
50 N	50 N	3.1	1.5	19.1	0.9	0.4	0.9	9.8	2.1	1.6	1.2	13.9	1.6
100 N	100 N	2.9	1.5	18.7	0.8	0.6	0.9	10.0	1.5	1.6	1.2	13.7	1.2
150 N	150 N	3.1	1.4	19.7	0.9	0.4	1.1	10.1	2.7	1.7	1.2	14.0	1.9
Soybean 20 N	Corn 0 N	2.8	1.3	20.1	1.8	0.4	1.1	10.5	3.1	1.5	1.2	14.6	2.6
	50 N	2.6	1.2	19.2	1.3	0.4	1.0	10.5	2.4	1.3	1.1	14.4	1.8
	100 N	2.7	1.2	19.6	0.8	0.4	1.1	10.2	2.1	1.5	1.1	14.4	1.5
	150 N	2.6	1.3	19.7	0.9	0.5	1.1	10.2	2.8	1.4	1.1	14.3	1.9
Faba bean 20 N	Corn 0 N	2.6	1.1	20.4	1.2	0.5	1.1	10.4	4.3	1.5	1.1	14.9	2.8
	50 N	2.8	1.3	19.8	1.0	0.5	1.0	10.4	2.5	1.5	1.2	14.6	2.1
	100 N	2.8	1.5	19.0	0.8	0.5	1.0	10.1	2.8	1.6	1.2	13.4	1.9
	150 N	2.7	1.4	19.6	1.3	0.4	1.0	10.0	3.3	1.4	1.2	14.2	2.4
Standard error		0.15	0.1	5	0.4	0.5	0.05	0.15	0.3	0.1	0.04	0.3	0.4

[z] Nitrogen (kg ha^{-1}) as NH_4NO_3.
[y] Means of four replications.

Table 5. Cu, Zn, Fe and Mn concentrations of the stover, ears and whole plants of second-year corn grown in monoculture or following soybean or faba bean, and fertilized with N at St-Anselme in 1988

First-year treatment (1987)	Second-year treatment (1988)	Stover				Ears				Whole plants			
		Cu	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu	Zn	Fe	Mn
		(mg kg^{-1})											
Corn 0 N	Corn 0 N[z]	13[y]	13	120	15	22	25	31	3	18	20	71	9
50 N	50 N	13	11	113	17	19	17	20	3	16	14	60	9
100 N	100 N	15	10	133	23	15	12	39	3	15	11	78	11
150 N	150 N	14	10	91	20	16	12	50	3	15	12	67	10
Soybean 20 N	Corn 0 N	12	11	116	16	19	14	36	3	16	13	69	8
	50 N	14	12	99	18	16	11	16	2	15	11	53	9
	100 N	14	9	119	20	16	11	34	3	15	11	70	9
	150 N	13	11	86	21	20	12	21	3	17	12	49	11
Faba bean 20 N	Corn 0 N	12	9	83	15	14	14	27	3	13	12	51	8
	50 N	13	10	98	19	17	14	23	3	15	12	55	10
	100 N	12	9	108	22	17	12	16	3	15	11	58	12
	150 N	14	10	89	20	18	12	49	4	16	11	67	11
Standard error		1.52	1.54	11.92	2.71	2.79	3.61	14.18	0.43	1.80	2.30	10.1	1.26

[z] Nitrogen (kg ha^{-1}) as NH_4NO_3.
[y] Means of four replications.

whole-plant Ca concentrations were higher for continuous corn than for corn preceded by faba bean or soybean, averaged across N levels (L × (C vs. S) and L × (C vs. F); Tables 2, 3 and 4). However, in general, these significant differences were small (Tables 3 and 4). There were no significant effects of previous crops and N fertilization on ear Ca concentrations.

The preceding crops and N fertilization had significant effects on the stover Mg concentrations (Tables 2, 3 and 4). In general, the stover Mg concentrations increased linearly in response to N application. In addition, averaged across N levels and at both locations, the stover Mg concentrations were significantly higher for continuous corn than for corn following soybean or faba bean (C vs. S and C vs. F; Tables 2, 3 and 4); however, these differences were small (Tables 3 and 4). The ear and the whole-plant Mg concentrations sometimes increased in response to N application (N_Q and N_L, respectively; Tables 2, 3 and 4). While at St-Anselme the ear Mg concentrations were similar among previous crops, they were generally significantly lower for continuous corn than for corn following soybean or faba bean at Deschambault (Tables 2, 3 and 4).

The corn K concentrations were also affected by previous crops and N application. Following both legumes and averaged across N levels and at both locations, the stover, ear and whole-plant K concentrations were significantly higher than for continuous corn (C vs. S and C vs. F; Tables 2, 3, and 4). Furthermore, the stover, ear and whole-plant K concentrations sometimes increased in response to N application (NQ, N_L and N_L and N_Q, respectively; Tables 2, 3 and 4).

At both locations, the stover P concentrations generally decreased linearly in response to N application (N_L significant, $P < 0.001$; Tables 3 and 4). Also, N fertilization had significant quadratic effects on the ear and whole-plant P concentrations (N_Q significant, $P < 0.05$; Tables 3 and 4). At St-Anselme and Deschambault, the stover and whole-plant Mn concentrations increased linearly with N application ($P < 0.001$ for both, Tables 5 and 6). In addition, averaged across N levels and at both locations, the stover and whole-plant Fe concentrations were generally significantly higher for continuous corn than for corn following faba bean (C vs. F significant, $P < 0.001$ and $P < 0.05$, respectively; Tables 5 and 6). The previous crops and N application had no significant effects on the

Table 6. Cu, Zn, Fe and Mn concentrations of the stover, ears and whole plants of second-year corn grown in monoculture or following soybean or faba bean, and fertilized with N at Deschambault in 1988

First-year treatment (1987)	Second-year treatment (1988)	Stover				Ears				Whole plants			
		Cu	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu	Zn	Fe	Mn
		(mg kg^{-1})											
Corn 0 N	Corn 0 N[z]	22[y]	13*	95	11	18	13	19	2	19	13	53	5
50 N	50 N	18	18	96	12	12	11	18	2	15	14	53	6
100 N	100 N	14	15	89	12	15	11	20	2	14	13	48	7
150 N	150 N	18	20	70	15	15	15	30	3	17	17	49	8
Soybean 20 N	Corn 0 N	19	14	84	7	16	13	23	3	18	14	50	5
	50 N	25	15	99	18	12	13	25	2	18	14	57	5
	100 N	15	13	93	12	15	13	36	2	15	13	62	7
	150 N	19	17	81	12	13	12	38	3	16	14	57	7
Faba bean 20 N	Corn 0 N	18	20	78	10	20	16	47	2	19	18	62	6
	50 N	16	14	66	7	9	12	22	2	12	13	42	4
	100 N	18	19	72	12	13	15	20	2	16	17	47	7
	150 N	22	18	72	12	20	13	20	2	20	15	44	7
Standard error		2.86	3.45	8.63	1.96	4.39	1.47	10.0	0.27	2.60	2.13	6.81	0.89

[z] Nitrogen (kg ha^{-1}) as NH_4NO_3.
[y] Means of four replications.

Table 7. Summary from the analyses of variance for corn cation uptake (kg ha^{-1}) at St-Anselme and Deschambault in 1988

Source of variation	df	Stover			Ears			Whole plants		
		Ca	Mg	K	Ca	Mg	K	Ca	Mg	K
						(Mean squares)				
Location (L)	1	(102)	(19.4)	(5643)	(5.46)	(18.9)	(20.6)	(155)	(77.0)	(6 344)
Rep[z] (within) L	6	14.0	1.47	536	6.44	7.00	101	7.25	10.2	467
PC[y]	2	83.8**	16.7**	3581	1.50	8.39*	498**	107*	33.8*	6 679***
C[x] vs. S[w]	1	24.1	18.4*	238	0.90	2.03	164	34.6	8.16	797
C vs. F[v]	1	62.7*	1.44	6364***	0.61	16.3**	986**	75.6*	27.5	12 361***
Nitrogen (N)	3	36.7*	26.2***	1184**	4.89**	14.3***	938***	65.3*	77.8***	4 174***
N_L[u]	1	93.7**	63.6***	3204***	12.1***	41.54***	2054***	173**	208***	10 389***
N_Q[t]	1	13.9	15.0*	350	1.07	1.34	747**	22.9	25.5	2 121
L × PC	2	107.58**	5.98	1098*	1.14	2.54	204	131***	7.72	2 231*
L × (C vs. S)	1	100.1**	5.23	316	1.15	3.38	13.4	122***	0.19	459
L × (C vs. F)	1	205***	11.5*	2158**	2.13	0.04	363	248**	13	4 291**
L × N	3	1.88	1.59	136	3.14	1.86	227	9.02	4.65	656
N × PC	6	18.7	1.56	568	1.17	2.92	184	17.71	5.73	1 230
N_L × (C vs. S)	1	8.18	0.87	47.6	0.01	1.04	3.9	1.32	3.75	24.2
N_L × (C vs. F)	1	14.8	0.00	366	2.54	11.2*	402*	5.16	11.1	1 535
N_Q × (C vs. S)	1	62.2*	2.80	1357*	0.58	3.91	490*	33.14	12	3 478*
N_Q × (C vs. F)	1	25.8	0.69	446	2.85	0.01	4.6	5.19	0.86	540
L × PC × N	6	12	3.44	144	0.59	0.53	20.5	15.39	3.80	201
Error	66	12.80	2.77	250.96	1.14	2.28	93.59	16.74	7.13	557.63
Total	95									

[z] Replications.
[y] Previous crops.
[x] Corn.
[w] Soybean.
[v] Faba bean.
[u] Linear effect of N.
[t] Quadratic effect of N.
*,**,***Significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

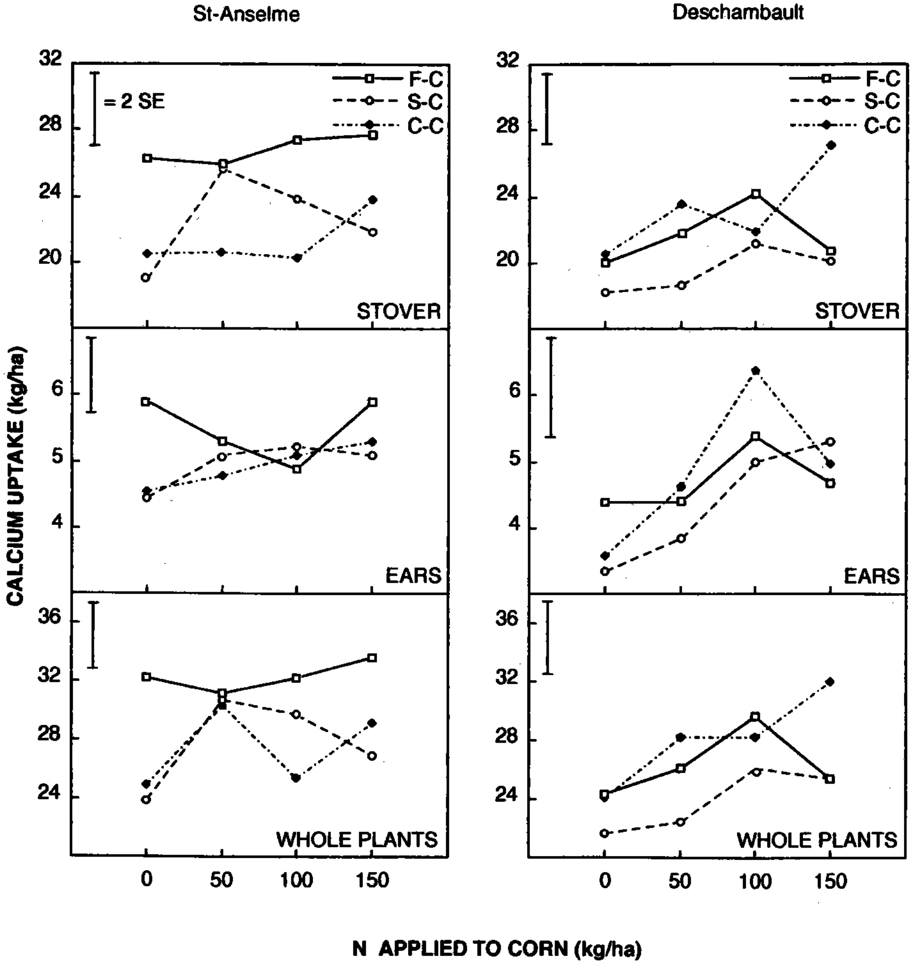

Fig. 1. Calcium uptake by the stover, ears and whole plants of forage corn following faba bean (F-C), soybean (S-C) and in monoculture (C-C) at St-Anselme and Deschambault. Vertical bars represent 2 standard errors of mean (n = 48).

stover, ear and whole-plant Cu and Zn concentrations (Tables 5 and 6).

Corn Mineral Uptake in 1988

There were significant differences among previous crops for cation uptake by subsequent corn (Table 7; Figs. 1, 2 and 3). At both locations, but especially at St-Anselme, the stover and whole-plant Ca uptake were higher when faba bean preceded corn than for continuous corn (C vs. F and L × (C vs. F); Table 7; Fig. 1). While at St-Anselme, the stover and whole-plant Ca uptake were generally higher for corn following soybean than for continuous corn, at Deschambault, they were higher for continuous corn than for corn preceded by soybean (L × (C vs. S); Table 7; Fig. 1). The ear and whole-plant Ca uptake increased linearly in response to N application, particularly at Deschambault, when corn followed soybean (N_L, Table 7; Fig. 1); these responses of ear and whole-plant Ca uptake to N can be described by the regression equations $Y = 3.32 + 0.014$ N ($P < 0.006$

and $R^2 = 0.42$), and $Y = 21.65 + 0.03$ N ($P < 0.005$ and $R^2 = 0.44$), respectively.

At both locations, but especially at Deschambault, the stover Mg uptake was significantly lower averaged across N levels for corn following soybean than for continuous corn (C vs. S; Table 7; Fig. 2). In addition, at both locations, the ear Mg uptake was higher for corn following faba bean than for continuous corn (C vs. F; Table 7; Fig. 2). Furthermore, at both locations, the stover, ear and whole-plant Mg uptake increased linearly in response to N application for continuous corn (N_L; Table 7; Fig. 2). For St-Anselme, the regression equations for stover, ear and whole-plant Mg uptake in response to N application were $Y = 9.78 + 0.016$ N ($P < 0.05$ and $R^2 = 0.24$), $Y = 9.60 + 0.012$ N ($P < 0.04$ and $R^2 = 0.25$) and $Y = 19.38 + 0.028$ N ($P < 0.04$ and $R^2 = 0.27$), respectively, while for Deschambault, these equations were $Y = 9.85 + 0.016$ ($P < 0.05$ and $R^2 = 0.24$), $Y = 7.56 + 0.024$ N ($P < 0.03$ and $R^2 = 0.28$), and $Y = 17.41 + 0.04$ N ($P < 0.02$ and $R^2 = 0.33$), respectively. Such a linear response to N application was also observed at Deschambault for the ear ($Y = 8.75 + 0.019$ N ($P < 0.007$ and $R^2 = 0.41$)) and whole-plant ($Y = 17.45 + 0.03$ N ($P < 0.01$ and $R^2 = 0.38$)) Mg uptake when corn was preceded by soybean, and for the whole-plant ($Y = 19.12 + 0.02$ N ($P < 0.04$ and $R^2 = 0.27$)) Mg uptake for corn following faba bean (Table 7; Fig. 2). At Deschambault, a significant response to N application was always observed for the stover Mg uptake when faba bean preceded corn (Fig. 2); the regression equation is $Y = 8.30 + 0.07$ N $- 32 \times 10^{-5}$ N^2 ($P < 0.009$ and $R^2 = 0.51$).

The stover, ear and whole-plant K uptake were higher for corn following faba bean than for continuous corn, particularly at St-Anselme (C vs. F, Table 7; Fig. 3). Also at St-Anselme, the stover and whole-plant K uptake were lower for continuous corn than for corn preceded by faba bean, while at Deschambault, the stover and whole-plant K uptake were generally similar for corn preceded by faba bean and for continuous corn (L × (C vs. F); Table 7; Fig. 3). At Deschambault, for continuous corn, the stover, ear and whole-plant K uptake increased linearly in response to N application (Table 7; Fig. 3); the respective regression equations for stover, ear and whole-plant K uptake in response to N application were $Y = 129.03 + 0.21$ N ($P < 0.015$ and $R^2 = 0.35$), $Y = 82.15 + 0.16$ N ($P < 0.005$ and $R^2 = 0.43$) and $Y = 221.18 + 0.37$ N ($P < 0.006$ and $R^2 = 0.42$). At Deschambault, the stover K uptake for corn preceded by soybean and the ear K uptake for corn preceded by faba bean always increased linearly with N application (Table 7; Fig. 3); the regression equations were $Y = 132.09 + 0.16$ N ($P < 0.05$ and $R^2 = 0.24$) and $Y = 91.38 + 0.08$ N ($P < 0.05$ and $R^2 = 0.23$), respectively. Following soybean, N applied to corn led to significant increases in ear and whole-plant K uptake at Deschambault; the respective regression equations were $Y = 79.75 + 0.51$ N -24×10^{-4} N^2 ($P < 0.004$ and $R^2 = 0.57$) and $Y = 206.06 + 1.01$ N $- 48 \times 10^{-4}$ N^2 ($P < 0.01$ and $R^2 = 0.48$).

At both locations, the stover and whole-plant P uptake generally increased in response to N application, but there were no significant differences among previous crops (data not shown). The Mn uptake by stover and whole-plant increased linearly with N application at St-Anselme and Deschambault, but the uptake of other micronutrients (Cu, Fe and Zn) was not affected by previous crops or by N application (data not shown).

DISCUSSION

Generally, corn mineral composition measured in corn monoculture or following legumes (Tables 3, 4, 5 and 6) did not vary from the critical composition values (Jones 1966). Furthermore, no visual symptoms of mineral deficiency (except for N in plots not receiving adequate N from fertilizer or from crop residues) were visible on corn plants.

At St-Anselme, the concentration and the uptake of Ca by stover and whole plants were higher following faba bean as previous crop

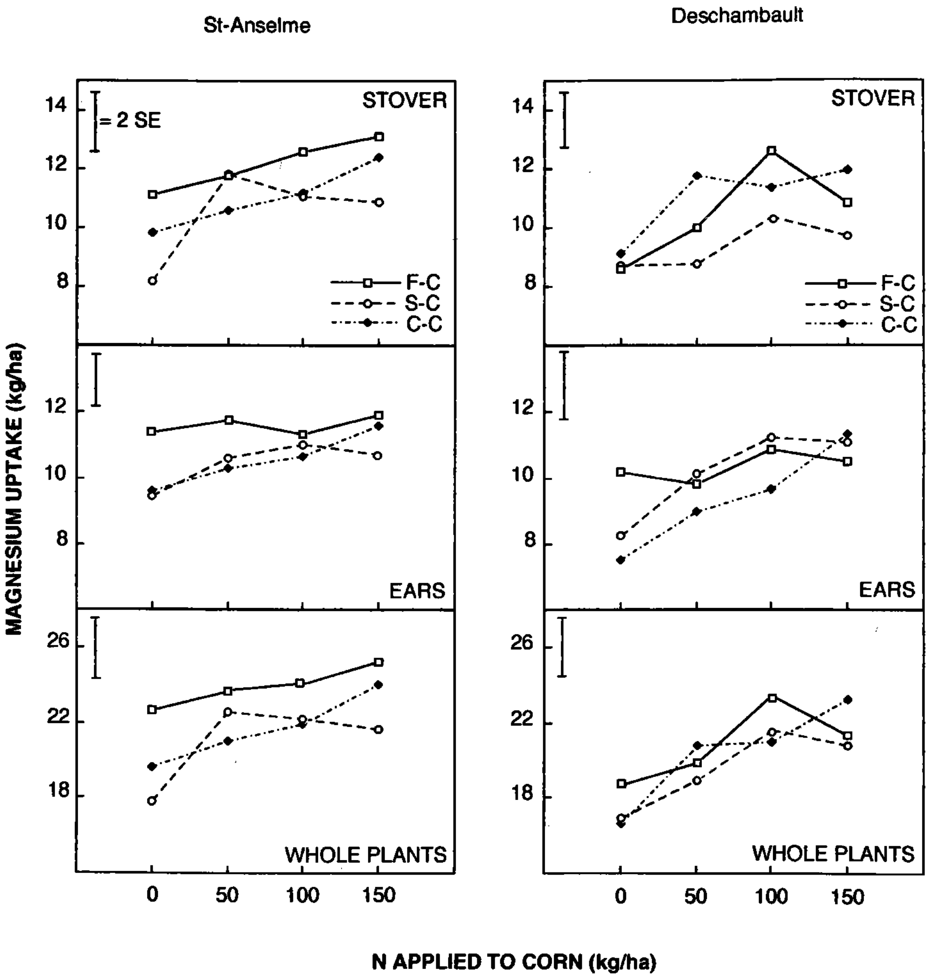

Fig. 2. Magnesium uptake by the stover, ears and whole plants of forage corn following faba bean (F-C), soybean (S-C) and in monoculture (C-C) at St-Anselme and Deschambault. Vertical bars represent 2 standard errors of mean (n = 48).

than following corn or soybean, although the levels of Ca measured in soil during the spring of 1988 did not show differences among treatments (Table 1). At this site, after grain harvest in 1987, 7535 kg ha^{-1} of faba bean residues were ploughed into the soil compared with 8334 kg ha^{-1} for soybean, while at Deschambault, the amounts were 7936 and 6547 kg ha^{-1} for faba bean and soybean, respectively. At St-Anselme, the amounts of Ca incorporated in soil were similar for both legumes (approximatively 65 kg ha^{-1}), but Ca uptake by soybean grains was higher than for faba bean grains (5.24 relative to 3.10 kg ha^{-1}); thus the pool of Ca availability for subsequent corn uptake at this site was probably lower following soybean than faba bean. In addition, several other hypotheses can be put forward to explain the differences between faba bean and corn and soybean as previous crops. Ca uptake may have been enhanced in response to the absorption of NO_3^- released by the decomposition and mineralization of faba bean residues to maintain cation-anion

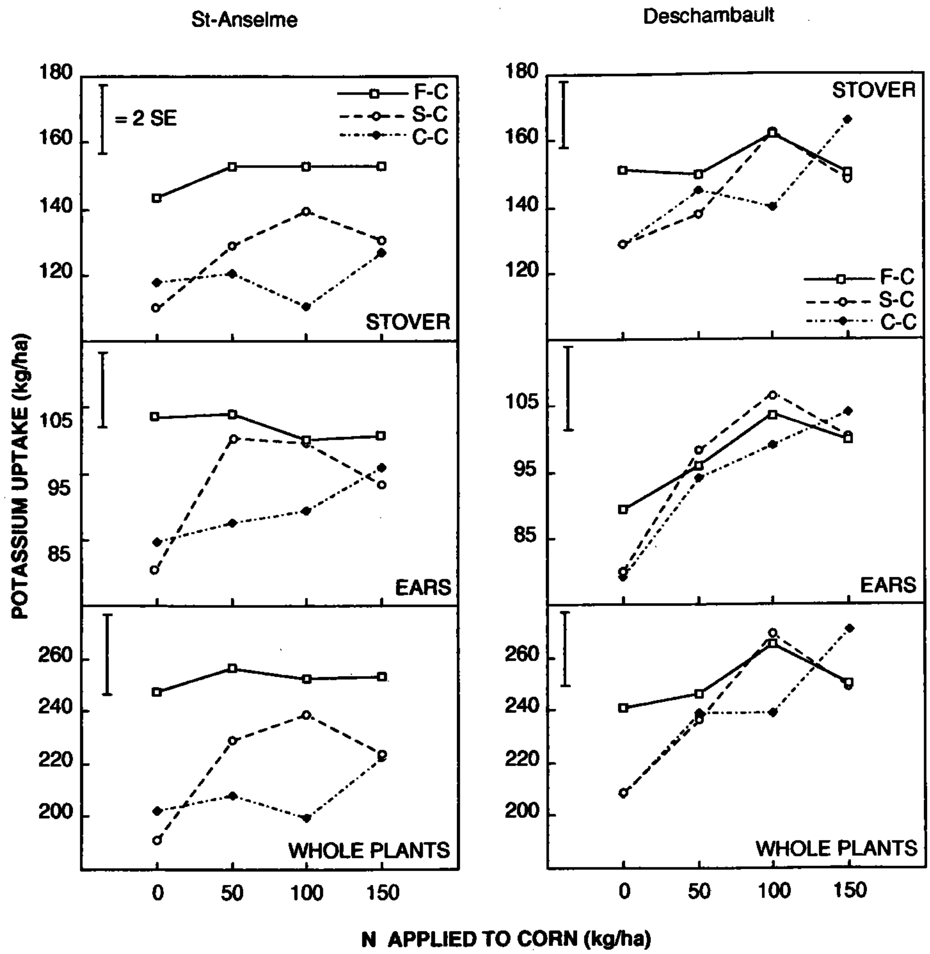

Fig. 3. Potassium uptake by the stover, ears and whole plants of forage corn following faba bean (F-C), soybean (S-C) and in monoculture (C-C) at St-Anselme and Deschambault. Vertical bars represent 2 standard errors of mean (n = 48).

balance in plants (Ebelhar et al. 1987). It has been also reported that *Rhizobium*, in addition to its ability to fix atmospheric N_2 in symbiosis with legumes, may enhance the uptake of other minerals to balance the nutritional needs of the host (Howell 1987). The data obtained in a study with peanut (*Arachis hypogaea* L.) cv. Florunner and eight rhizobial strains of the cowpea complex indicated significant influences of certain strains on the mineral concentrations of nodules and seeds (Howell 1987). Groffman et al. (1987), studying the effect of a winter legume on mineral cycling in a humid subtropical agroecosystem, found higher levels of N, P, K, Ca and Mg in clover than rye; they also found that the subsequent sorghum tissue cation and P concentrations tended to be higher following clover than rye.

In our study, similar quantities of K were applied in plots at each location following all previous crops. Nevertheless, at both locations and particularly at St-Anselme, the previous crops, particularly faba bean, affected the concentration and uptake of this mineral by the subsequent corn (Tables 2, 3, 4 and 7; Fig. 3) although soil K concentrations in spring 1988 did not indicate an increased availability of this nutrient for corn following faba bean, except at Deschambault (Table 1). At both locations, it is interesting to note that K export by soybean grains was higher than that of faba bean (55 relative to 33 kg ha^{-1}), while the presumed amounts of K brought by residues were similar for both legumes (approximatively 100 kg ha^{-1}). Although not confirmed by soil analyses in spring 1988, the greater depletion of soil K by the harvest of soybean grains in the 1987 growing season could partly explain the higher concentrations and uptake of K by corn subsequent to faba bean, particularly at St-Anselme.

In this experiment, the alleged greater availability of Mg in soil in the soybean treatment compared to other previous crops (Table 1) did not significantly affect this cation concentration and uptake by subsequent corn. Furthermore, although the amounts of Mg that could potentially be released from the decomposing faba bean residues (25 and 27 kg ha^{-1} of Mg at St-Anselme and Deschambault, respectively) were significantly higher than those of soybean (11 and 9 kg ha^{-1} of Mg at St-Anselme and Deschambault, respectively), it did not increase this cation concentration in subsequent corn. At Deschambault, the Mg uptake generally increased with N application and all previous crops (Fig. 2) and this effect of N would be the same as with Ca and K uptake, i.e., to maintain cation-anion balance (Blevins et al. 1974; Mengel and Kirby 1982).

In the present study, P was supplied at both locations as recommended and in the same amounts for all the previous crops. Furthermore, soil P concentrations in spring 1988 were similar for all previous crops at St-Anselme and Deschambault (Table 1). At both locations, the lower P concentrations in stover compared to ears can be partly attributed to the export of this mineral from stover to grains as it can occur during grain filling (Marschner 1986). At St-Anselme and Deschambault, the previous crops did not affect P uptake, and the effects of N were inconsistent.

The higher Fe concentrations of stover at both locations and the higher concentrations of Fe measured in whole plants at St-Anselme in corn monoculture than following faba bean, could be attributed in part to dilution effects due to higher corn DMY after faba bean than for continuous corn (Paré et al. 1992).

In conclusion, N application had significant effects on concentrations and uptake of some minerals; this could probably be due to better corn root growth and exploration of a larger volume of soil, or to the maintainance of the cation-anion balance. Soybean and faba bean as previous crops did not significantly influence micronutrients (Cu, Fe, Zn and Mn) uptake by subsequent corn crop, but their effects on the absorption of some cations (Ca, Mg and K) were noteworthy. Indeed, previous faba bean increased the concentration and uptake of K, and the uptake of Ca and Mg by a subsequent forage corn crop. It is therefore apparent from these results that faba bean as previous crop, in addition to the supply of N to subsequent corn (Paré et al. 1992), can enhance the uptake of other mineral ions by subsequent corn. Previous soybean influenced Ca and K concentrations to a lesser extent than faba bean, especially at St-Anselme. This lesser effect of soybean compared to faba bean could be related to its soil N depletion (Paré et al. 1992) which did not promote yields as high as those of corn following faba bean, reducing the requirements of counterions for NO_3^- uptake. Furthermore, generally, all mineral concentrations and uptake by soybean grains were higher than those measured in faba bean (data not shown), suggesting that the export of nutrients by soybean grains could contribute to reduce their potential availability more than faba bean for subsequent crops. Nevertheless, the uptake of the measured minerals by whole-plant corn was considerably higher than by soybean or faba bean grains in 1987 (data not shown). This could also have contributed to the observed rotation effects not due to N, for both soybean and faba bean. Rotation effects observed with both legumes, but particularly with faba bean (Paré et al. 1992), can thus be explained partly by an improvement of mineral nutrition of subsequent corn.

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