Forage-corn production and N-fertilizer replacement values following 1 or 2 years of legumes

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Paré, T., Chalifour, F.-P., Bourassa, J. and Antoun, H. 1993. **Forage-corn production and N-fertilizer replacement values following 1 or 2 years of legumes.** Can. J. Plant Sci. **73**: 477–493. The costs of N fertilizer and concern for sustainable agriculture have led to renewed interest in the use of legumes as a source of N for succeeding non-legume crops. In this regard, field experiments were conducted in 1987, 1988 and 1989 on a Rivière-du-Loup sandy gravelly loam (Ferro-Humic Podzol) at St-Anselme and on a Chaloupe silty loam (Orthic Humic Gleysol) at Deschambault in eastern Quebec, Canada, to determine the effects of 1 or 2 years of faba bean (*Vicia faba* L.) Outlook and soybean (*Glycine max* [L.] Merr.) Maple Amber on subsequent forage-corn (*Zea mays* L.) Pioneer 3979 dry matter yields (DMY) and N uptake, and the N-fertilizer replacement values (NFRV) of the different crop sequences. Corn in monoculture or following a legume was fertilized with 0, 50, 100 or 150 kg N ha^{-1}, and legumes received 20 kg N ha^{-1} as NH_4NO_3. In 1989, at both locations, the DMY and N uptake of forage corn in monoculture or following 2 consecutive years of soybean, or subsequent to soybean and faba bean grown 2 years previously, increased linearly with N application. After 2 consecutive years of faba bean, the DMY were not affected by increasing fertilization, but the N uptake generally increased proportionally to N application. The estimated NFRV (on a DMY basis) after 2 consecutive years of faba bean varied from 60 to 125 kg N ha^{-1} at St-Anselme, and from 100 to 110 kg N ha^{-1} at Deschambault for the ears and stover, respectively. The NFRV estimated for the same cropping sequence varied from 122 to 129 kg N ha^{-1} at St-Anselme and from 104 to 131 kg N ha^{-1} at Deschambault, for the stover and ears, respectively, on the basis of N uptake. For 2 consecutive years of soybean, it averaged 14 kg N ha^{-1} at St-Anselme and 33 kg N ha^{-1} at Deschambault, on the basis of the DMY; when based on the N uptake, the NFRV of 2 consecutive years of soybean varied from 14 to 21 kg N ha^{-1} at St-Anselme and from 0 to 15 kg N ha^{-1} at Deschambault for the stover and ears, respectively. The average NFRV (based on the DMY) for faba bean grown 2 years previously were 17 kg N ha^{-1} at St-Anselme but NFRV varied from 0 to 16 kg N ha^{-1} at Deschambault for stover and ears, respectively; on the basis of N uptake, the NFRV for the same crop sequence averaged 24 kg N ha^{-1} at St-Anselme, but varied from 0 to 15 kg N ha^{-1} at Deschambault for the stover and ears, respectively.

Key words: Corn, faba bean, soybean, crop sequence, N fertilization

Paré, T., Chalifour, F.-P., Bourassa, J. et Antoun H. 1993. **Production de maïs-fourrage et valeurs de remplacement en fertilisant azoté après une ou deux années consécutives de légumineuses.** Can. J. Plant Sci. **73**: 477–493. Les coûts des fertilisants azotés et les préocupations concernant une agriculture durable ont renouvelé l'intérêt de l'utilisation de légumineuses comme source d'N pour les cultures subséquentes de non légumineuses. Dans cette optique, des expériences au champ ont été réalisées en 1987, 1988 et 1989 sur un loam sablo-graveleux de la série Rivière-du-Loup (podzol ferro-humique) à St-Anselme et sur un loam argileux de la série Chaloupe (gleysol humique orthique) à Deschambault, dans l'est du Québec, pour déterminer les effets d'une ou de deux années consécutives de féverole (*Vicia faba* L.) Outlook et de soja (*Glycine max* [L.] Merr.) Maple Amber sur les rendements en

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matière sèche et l'absorption d'N de la culture subséquente de maïs fourrage (*Zea mays* L.) Pioneer 3979, et les valeurs de remplacement en fertilisant azoté (VRFA) des différentes séquences culturales. Le maïs en monoculture ou subséquent à une légumineuse a été fertilisé avec 0, 50, 100 ou 150 kg N ha^{-1}, et les légumineuses ont reçu 20 kg N ha^{-1} sous forme de NH_4NO_3. En 1989, aux deux sites, les rendements en matière sèche (RMS) et l'absorption d'N du maïs fourrage en monoculture ou subséquent à deux années consécutives de soja, ou subséquent au soja ou à la féverole cultivés deux années auparavant, ont augmenté linéairement avec l'application d'N. Après deux années consécutives de féverole, les RMS du maïs n'ont pas été influencés par l'apport d'N, mais l'absorption d'N du maïs dans cette séquence culturale a augmenté proportionnellement à l'augmentation des doses d'N. Les VRFA estimées (sur la base des RMS) après deux années consécutives de féverole ont varié de 60 à 125 kg N ha^{-1} à St-Anselme et de 100 à 110 kg N ha^{-1} à Deschambault pour les épis et les cannes, respectivement. Sur la base de l'absorption d'N, les VRFA estimées pour la même séquence culturale ont varié de 122 à 129 kg N ha^{-1} à St-Anselme et de 104 à 131 kg N ha^{-1} à Deschambault, pour les cannes et les épis, respectivement. Pour deux années consécutives de soja, les VRFA étaient en moyenne de 14 kg N ha^{-1} à St-Anselme et de 33 kg N ha^{-1} à Deschambault, sur la base des RMS; basées sur l'absorption d'N, les VRFA de deux années consécutives de soja ont varié de 14 à 21 kg N ha^{-1} à St-Anselme et de 0 à 15 kg N ha^{-1} à Deschambault pour les cannes et les épis, respectivement. Les VRFA moyennes (basées sur le RMS) pour la féverole cultivée deux années auparavant étaient de 17 kg N ha^{-1} à St-Anselme mais ont varié de 0 à 16 kg N ha^{-1} à Deschambault pour les cannes et les épis, respectivement; sur la base de l'absorption d'N, les VRFA pour la même séquence culturale étaient en moyenne de 24 kg N ha^{-1} à St-Anselme, mais ont varié de 0 à 15 kg N ha^{-1} à Deschambault pour les cannes et les épis, respectivement.

Mots clés: Maïs, féverole, soja, séquence culturale, fertilisation azotée

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The benefits of crop rotations including legumes and corn (*Zea mays* L.) have been recognized for a long time (Bruulsema and Christie 1987; Hargrove and Frye 1987). Although this practice has decreased, particularly in North America, during the past decades due to the intensive use of abundant and inexpensive N fertilizer (Blevins et al. 1990), the increased production costs of N fertilizer and greater interest in organic farming (Heichel and Barnes 1984) have led to renewed interest in rotations.

Nevertheless, the benefits of growing a legume before a subsequent nonlegume is influenced by how the legume is managed for return of N to the soil (Heichel 1987). Generally, residues from annual pulses such as soybean (*Glycine max* [L.] Merr.) or faba bean (*Vicia faba* L.) are incorporated in the soil after grain harvest (Senaratne and Hardarson 1988; Wright 1990; Paré et al. 1992) and the succeeding cereal crops are grown on decomposing residues. Subsequent yield increases observed following pulses have mainly been attributed to N availability from their decomposing residues (Claassen and Kissel 1984; Hanson et al. 1988; Paré et al. 1992); however, other factors not directly associated with legume N and called rotation effects (Baldock et al. 1981) could explain yield enhancement (Baldock et al. 1981; Paré et al. 1992). According to Baldock et al. (1981), in terms of yield, the total rotation effect is the yield differential without N application, the rotation effect is the yield differential at the highest N level, and the N-rotation effect is the total rotation effect minus the rotation effect.

Yield responses to previous legumes can be expressed on the basis of N-fertilizer replacement values (NFRV), defined as the amount of N fertilizer required by a non-legume crop in monoculture to produce yields equivalent to those produced after incorporation of a legume (Hesterman 1988). Wright (1990) reported NFRV of 120, 100 and 80 kg N ha^{-1} for faba bean, field pea (*Pisum sativum* L.) and lentil (*Lens culinaris* Medic), respectively, in barley (*Hordeum vulgare* L.) production. Clegg (1982) estimated a benefit of soybean to subsequent grain sorghum (*Sorghum bicolor* [L.] Moench) in Nebraska equal to 76 kg N ha^{-1}. In Kansas, Claassen and Kissel (1984) found that the NFRV of soybean was equivalent to 24 kg N ha^{-1} for the subsequent corn production, whereas they were 33 and 57 kg N ha^{-1} for sorghum stover and grain dry-matter yields (DMY), respectively. In an experiment as part of a larger crop rotation study, Paré et al. (1992) estimated a NFRV (for corn DMY) higher than 150 kg N ha^{-1} at St-Anselme, and between 22 kg N ha^{-1} (for corn ear DMY) and 42 kg N ha^{-1} (for corn stover DMY) at Deschambault for faba bean, but less than 0 kg N ha^{-1} for soybean at both sites; in this study, the corn residues were removed from the plots.

Investigations reporting a N contribution of 2 consecutive years of annual pulses, or the N benefit from pulses grown for 1 year and then followed by 2 consecutive cereal crops, are very few. It can be postulated that the incorporation of residues from annual pulses grown and harvested for grain during 2 consecutive years, supplies more N to a succeeding non-legume crop than a 1 year stand and that a second non-legume crop recovers a part of the N from legume residues added to soil 2 years previously and upon which a first non-legume crop was produced. Wright (1990) reported a continuing effect of pulse and barley residues from crops produced 2 years previously; he noted that wheat (*Triticum aestivum* L.) productivity and N uptake were greater on plots that had had faba bean or field pea than on those having had lentil or barley. Our objectives in this study were to evaluate (i) the residual effects of 2 consecutive years of faba bean or soybean on forage-corn production, (ii) the residual effects of faba bean and soybean grown 2 years previously for a second succeeding forage corn crop, and (iii) the NFRV of these previous crop sequences on the basis of dry-matter production and N uptake of corn.

MATERIALS AND METHODS

Crop rotation trials were conducted during the 1987, 1988 and 1989 growing seasons on a Rivière-du-Loup sandy gravelly 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 and their cropping history were described by Paré et al. (1992). Corn Pioneer 3979, faba bean Outlook and soybean Maple Amber were used in these field experiments. Plot sizes, plant densities, herbicide and N applications and other cultural practices for 1987 and 1988 growing seasons were previously described by Paré et al. (1992).

In 1989, corn (hybrid Pioneer 3979) was grown in continuous monoculture (C-C-C), and in four different crop sequences (i) soybean-corn-corn (S-C-C); (ii) soybean-soybean-corn (S-S-C); (iii) faba bean-corn-corn (F-C-C); and (iv) faba bean-faba bean-corn (F-F-C). Each replication consisted of four plots of monoculture and of each legume-corn sequence. Corn plots were fertilized with a total of 0, 50, 100 or 150 kg N ha^{-1} applied as previously described (Paré et al. 1992). Thus, the experimental design consisted of 20 treatments arranged in a randomized complete block design replicated four times at each location. Before corn planting, 23.6 kg ha^{-1} of P and 134.9 kg ha^{-1} of K at St-Anselme and 39.3 kg ha^{-1} of P and 99.6 kg ha^{-1} of K at Deschambault were applied and disced in as recommended by the Conseil des Productions Végétales du Québec (CPVQ 1984). Total precipitation was 638 mm at St-Anselme, which was 51 mm below the normal, and 771 mm at Deschambault, which was 67 mm above the normal; at both sites, corn heat units (CHU) (2839 and 3005, at St-Anselme and Deschambault, respectively) were higher than normal. Pre-emergence herbicides (atrazine (1.5 kg a.i. ha^{-1}) and metolachlor (1.8 kg a.i. ha^{-1})) were used for corn as recommended by the CPVQ. Three central rows of each corn plot were harvested with a forage harvester after the ears were harvested by hand, to evaluate the DMY of the ears, stover and whole plants. Plant fractions were chopped and samples were dried at 70°C, weighed and ground to pass through a 32-mesh sieve. The N concentration was determined on ground samples after Kjeldahl digestion using a Technicon autoanalyzer (Techicon Industrial System, Tarrytown, NY) (Morgan et al. 1966). The NFRV were quantified following the method described by Hesterman (1988). The procedure involves the generation of a N-fertilizer response curve for a nonlegume monoculture, and the comparison of the yield (or N uptake) of a nonlegume crop following a legume without N-fertilizer application with yield (or N uptake) from the response curve. The equivalent amount of N-fertilizer required to produce such a similar yield in monoculture is considered the NFRV of the legume.

Statistical analyses were carried out using the GLM procedure from the 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 reported if the error variances were homogeneous. The orthogonal contrasts were calculated for corn following different cropping systems, to determine significant linear or quadratic trends in corn N response. Regression equations for DMY (Mg ha^{-1}) and N uptake (kg ha^{-1}) as a function of fertilizer N rate (kg ha^{-1}) for each cropping system were calculated for the stover, ears and whole plants on the basis of orthogonal trend comparisons.

RESULTS

Dry Matter Yields of Forage Corn

Averaged across all N levels and locations, the corn stover, ear and whole-plant DMY were higher with two consecutive years of faba bean (F-F-C) than with corn grown in monoculture (C-C-C) (Table 1; Figs. 1 and 2). Significant corn DMY increases were observed following 2 consecutive years of faba bean at 0 kg N ha^{-1} at both locations, compared with the monoculture (Figs. 1 and 2); in addition, at St-Anselme, there were rotation effects at other N levels for ear and whole plant DMY following this crop sequence, in spite of a decrease

Table 1. Summary from the analyses of variance for forage corn dry-matter yields and N uptake at St-Anselme and Deschambault in 1989

		Dry-matter yields			Nitrogen uptake		
Source of variation	df	Stover	Ears	Whole plants	Stover	Ears	Whole plants
		(Means squares)					
Location (L)	1	(253)	(6.30)	(339)	(31 155)	(2 041)	(48 978)
Rep^z (Within) L	6	7.35	6.32	25	474	787	1 953
PC^y	4	3.29***	4.64***	15.42***	1 271***	2 176***	6 461***
C^x vs. S^w	1	0.025	0.16	0.29	12.79	14.12	53.80
C vs. F^v	1	0.30	1.36	2.87	61.67	535	1 036*
C vs. 2S^u	1	0.77	4.10*	8.30*	401**	731**	2 214**
C vs. 2F^t	1	10***	14.67***	48.59***	3 843***	6 798***	20 201***
Nitrogen (N)	3	17.50***	50.54***	127***	7 603***	11 183***	36 783***
N_L^{s}	1	47.20***	133.21***	340***	22 433***	31 669***	106 674***
N_Q^{r}	1	5.16***	17.34***	41.22***	277***	1 654***	3 254***
L × PC	4	0.39	0.56	1.57	148*	229	593*
L × (C vs. 2F)	1	0.11	0.40	0.89	503**	471	1 081**
L × N	3	0.16	3.35**	4.77*	416***	306	557
L × N_L	1	0.18	8.96**	11.80*	781***	529	17.19
L × N_Q	1	0.17	0.11	0.57	386**	212	1 162*
PC × N	12	0.77*	2.38**	5.28**	200***	464***	1 090***
(C vs. S) × N_L	1	0.24	1.97	3.49	95.22	232	624
(C vs. F) × N_L	1	0.00	0.02	0.02	12.85	0.16	14.80
(C vs. 2S) × N_L	1	0.07	1.26	1.98	11.94	270	168
(C vs. 2F) × N_L	1	2.94**	9.63***	23.52***	598***	1 653***	4 312***
(C vs. 2S) × N_Q	1	0.004	0.02	0.006	223*	260	965*
(C vs. 2F) × N_Q	1	0.04	3.80*	4.58	82.17	269	72.93
L × PC × N	12	0.24	0.61	0.97	59.66	145	136
Error	114	0.34	0.80	1.75	51.51	136	238
CV (%)		8.97	11.34	12.43	12.76	12.06	10.09
Total	159						

[z] Replications.
[y] Previous crops.
[x] Corn.
[w] Soybean.
[v] Faba bean.
[u] Two consecutive years of soybean.
[t] Two consecutive years of faba bean.
[s] Linear effect of N.
[r] Quadratic effect of N.
*,**,*** Significant at the 0.05, 0.01 and 0.001 probability levels, respectivley.

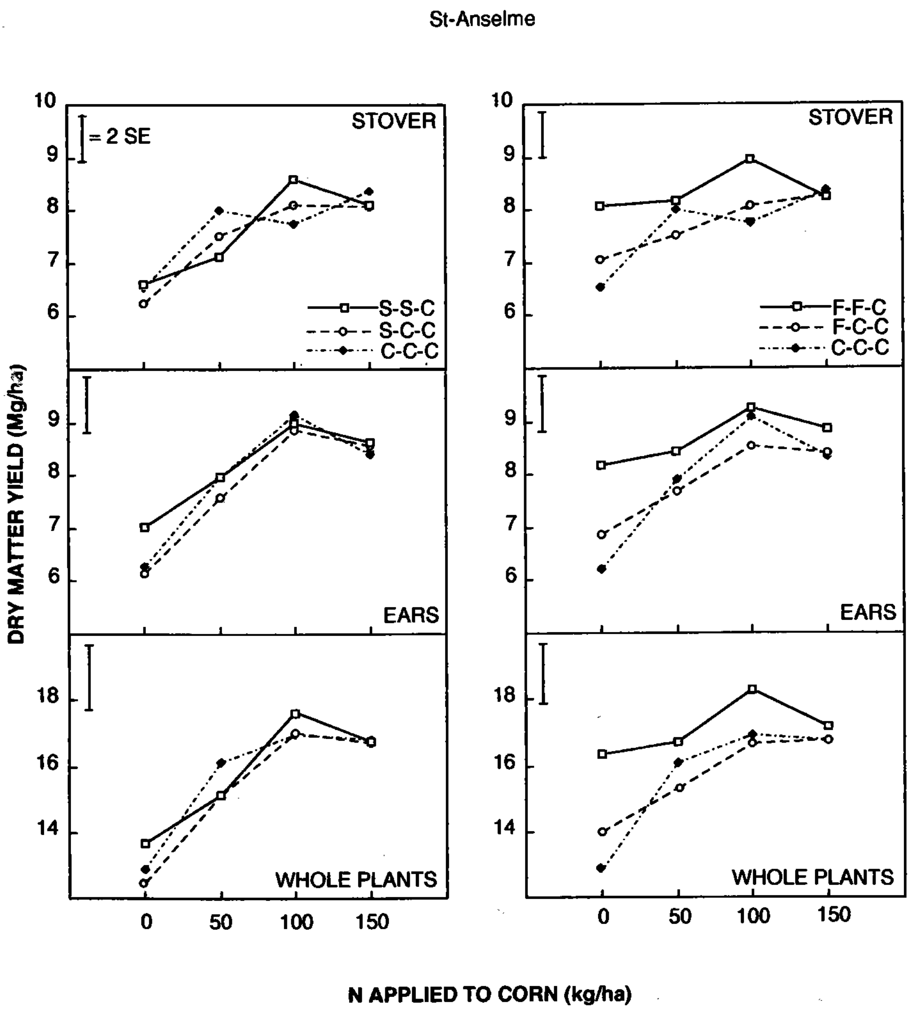

Fig. 1. Dry-matter yields of forage corn after 2 consecutive years of faba bean (F-F-C) and soybean (S-S-C), after faba bean (F-C-C) and soybean (S-C-C) grown 2 years previously and in monoculture (C-C-C) at St-Anselme. Vertical bars represent 2 standard errors of mean (n = 48).

observed in DMY at the highest N rate (Fig. 1). Although there were no significant differences (averaged across all N levels) between corn grown in monoculture (C-C-C) and faba bean grown 2 years earlier (F-C-C) as previous crop sequences, at St-Anselme, corn following faba bean in the F-C-C crop sequence nevertheless outyielded corn from the monoculture at 0 kg N ha^{-1} for the stover, ear and whole-plant DMY (Table 1; Fig. 1). The ear and the whole-plant DMY were generally higher after 2 consecutive years of soybean (S-S-C) than after corn grown in monoculture, especially at Deschambault (Table 1; Figs. 1 and 2).

The DMY increased significantly with the N application, and the degree of response varied among previous crop sequences (Tables 1 and 2; Figs. 1 and 2). For all crop sequences, except after 2 consecutive years of faba bean (F-F-C), the linear (N_L) or quadratic (N_Q) components of the N response

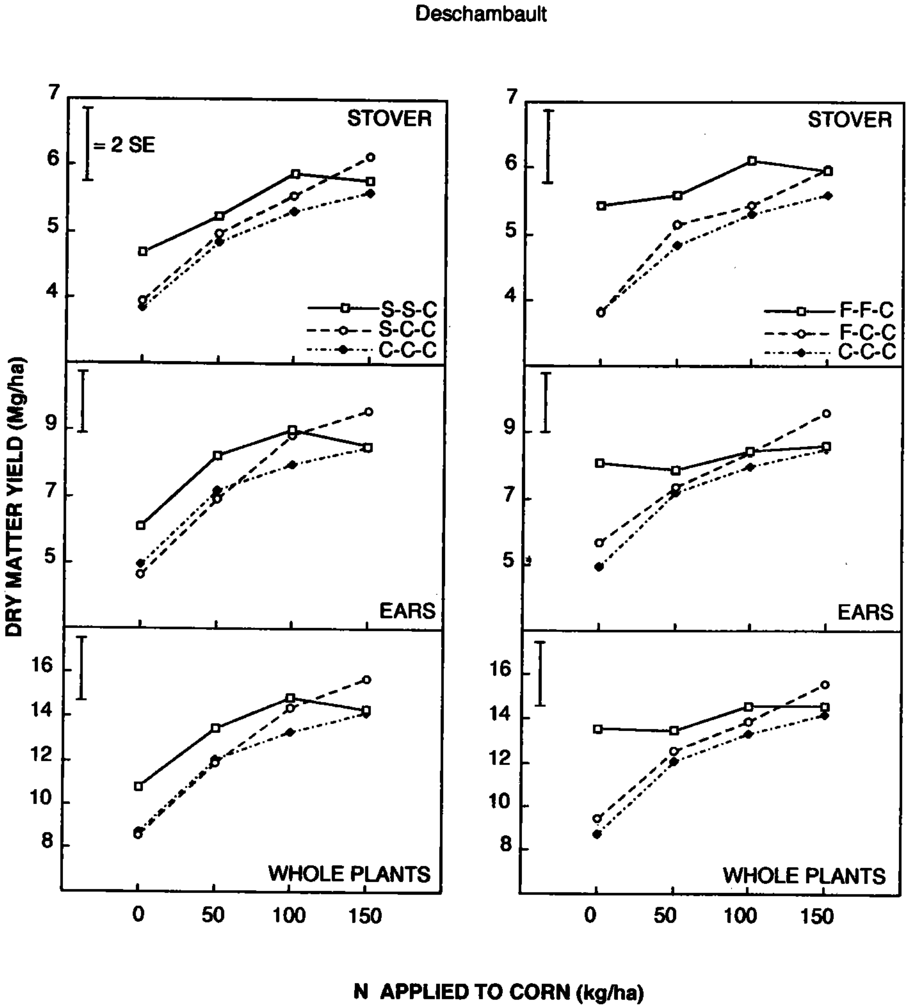

Fig. 2. Dry-matter yields of forage corn after 2 consecutive years of faba bean (F-F-C) and soybean (S-S-C), after faba bean (F-C-C) and soybean (S-C-C) grown 2 years previously and in monoculture (C-C-C) at Deschambault. Vertical bars represent 2 standard errors of mean (n = 48).

were significant (Tables 1 and 2; Figs 1 and 2); indeed, at both sites, the N application did not affect the DMY of corn following 2 consecutive years of faba bean compared with corn grown in monoculture, for which the response to N fertilization was similar to other previous crop sequences ((C vs. 2F) × N_L and (C vs. 2F) × N_Q), (Table 1; Figs. 1 and 2).

Following corn or other previous crops (except the F-F-C sequence), the ear and whole-plant DMY generally increased more with the N application at Deschambault than at St-Anselme (L × N_L; Tables 1 and 2; Figs. 1 and 2); this seemed more important for corn from the S-C-C, F-C-C, and C-C-C sequences, albeit the second-order interaction L × PC × N was not significant (Table 1; Figs. 1 and 2).

N Concentrations of Forage Corn

Previous crop sequences had significant effects on the corn stover, ear and whole-plant

Table 2. Regression equations for dry-matter yields (Y) of corn as a function of N rates (N) for crop sequences at St-Anselme and Deschambault in 1989

Crop sequences	Plant fraction	Equations	$Pr>F$	R^2
		St-Anselme		
C[z]-C-C	Stover	$Y = 6.87 + 0.10\ N$	0.0037	0.46
	Ears	$Y = 6.22 + 0.052\ N - 0.0002\ N^2$	0.0001	0.76
	Whole plants	$Y = 12.89 + 0.07\ N - 0.0003\ N^2$	0.0001	0.76
S[y]-C-C	Stover	$Y = 6.58 + 0.012\ N$	0.0009	0.56
	Ears	$Y = 6.08 + 0.043\ N - 0.0002\ N^2$	0.0021	0.61
	Whole plants	$Y = 12.34 + 0.075\ N - 0.0003\ N^2$	0.0001	0.77
S-S-C	Stover	$Y = 6.45 + 0.027\ N - 0.0001\ N^2$	0.014	0.48
	Ears	$Y = 6.94 + 0.03\ N - 0.0001\ N^2$	0.0052	0.55
	Whole plants	$Y = 13.40 + 0.06\ N - 0.0002\ N^2$	0.0015	0.63
F[x]-C-C	Stover	$Y = 7.10 + 0.008\ N$	0.0005	0.59
	Ears	$Y = 7.10 + 0.011\ N$	0.0018	0.51
	Whole plants	$Y = 14.21 + 0.039\ N$	0.0004	0.61
F-F-C	Stover	$Y = 8.18 + 0.025\ N$	0.28	0.08
	Ears	$Y = 8.32 + 0.006\ N$	0.21	0.11
	Whole plants	$Y = 16.50 + 0.008\ N$	0.17	0.12
		Deschambault		
C-C-C	Stover	$Y = 4.03 + 0.011\ N$	0.0057	0.43
	Ears	$Y = 5.41 + 0.023\ N$	0.0001	0.68
	Whole plants	$Y = 9.44 + 0.035\ N$	0.0002	0.64
S-C-C	Stover	$Y = 4.07 + 0.014\ N$	0.018	0.33
	Ears	$Y = 4.99 + 0.033\ N$	0.0001	0.68
	Whole plants	$Y = 9.06 + 0.048\ N$	0.0008	0.56
S-S-C	Stover	$Y = 4.80 + 0.008\ N$	0.007	0.41
	Ears	$Y = 6.10 + 0.055\ N - 0.0002\ N^2$	0.0019	0.61
	Whole plants	$Y = 11.54 + 0.024\ N$	0.0014	0.53
F-C-C	Stover	$Y = 4.07 + 0.014\ N$	0.011	0.38
	Ears	$Y = 5.81 + 0.025\ N$	0.0012	0.54
	Whole plants	$Y = 9.88 + 0.039\ N$	0.0025	0.49
F-F-C	Stover	$Y = 5.46 + 0.004\ N$	0.26	0.09
	Ears	$Y = 7.93 + 0.004\ N$	0.40	0.05
	Whole plants	$Y = 13.38 + 0.008\ N$	0.32	0.07

[z] Corn.
[y] Soybean.
[x] Faba bean.

N concentrations (Tables 3 and 4), especially after 2 consecutive years of faba bean (C vs. 2F, Table 3); with the F-F-C crop sequence, the stover, ear and whole-plant N concentrations were higher than those obtained after corn, especially at St-Anselme (L × (C vs. 2F), Tables 3 and 4). The stover and whole-plant N concentrations were higher after 2 consecutive years of soybean (S-S-C) than after corn (C-C-C), especially at St-Anselme (L × (C vs. 2S), Tables 3 and 4). At both locations, the N concentrations of stover, ears and whole plants increased linearly with the N application following all previous crops

Table 3. Summary from the analyses of variance for N concentration (%) of forage corn at St-Anselme and Deschambault in 1989

Source of variation	df	Stover	Ears	Whole plants
		(Mean squares)		
Locations (L)	1	(0.38)	(0.02)	(0.02)
Replications (within) L	6	0.03	0.009	0.01
Previous crops (PC)	4	0.09***	0.07***	0.09***
C[z] vs. S[y]	1	0.003	0.001	0.001
C vs. F[x]	1	0.007	0.02	0.009
C vs. 2S[w]	1	0.04**	0.0005	0.01
C vs. 2F[v]	1	0.31***	0.18***	0.24***
Nitrogen (N)	3	0.70***	0.09***	0.34***
N_L[u]	1	2.11***	0.18***	1.02***
N_Q[t]	1	0.002	0.26***	0.006
L × PC	4	0.01**	0.03*	0.03***
L × (C vs. S)	1	0.01	0.05*	0.04**
L × (C vs. 2S)	1	0.03**	0.03	0.03*
L × (C vs. 2F)	1	0.06***	0.13***	0.12***
PC × N	12	0.02***	0.01	0.010*
(C vs. 2F) × N_L	1	0.05***	0.008	0.04**
(C vs. S) × N_Q	1	0.03**	0.0004	0.0005
(C vs. F) × N_Q	1	0.006	0.007	0.001
(C vs. 2S) × N_Q	1	0.03**	0.04*	0.02
(C vs. 2F) × N_Q	1	0.009	0.003	0.000003
L × N	3	0.03***	0.01	0.02**
L × N_L	1	0.03**	0.02	0.04**
L × N_Q	1	0.04**	0.009	0.02*
L × PC × N	12	0.005	0.007	0.002
Error	114	0.004	0.01	0.005
CV (%)		7.46	8.65	6.85
Total	159			

[z] Corn.
[y] Soybean.
[x] Faba bean.
[w] Two consecutive years of soybean.
[v] Two consecutive years of 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.

(Tables 3 and 4), except following 2 consecutive years of faba bean (F-F-C), after which the N application did not influence the stover and whole-plant N concentrations compared to corn as a previous crop ((C vs. 2F) × N_L, Tables 3 and 4). There were greater increases in stover and whole-plant N concentrations at St-Anselme than at Deschambault with N application (Tables 3 and 4).

N Uptake of Forage Corn

The forage-corn N uptake varied significantly according to preceding crops and N application (Table 1; Figs 3 and 4). Corn in monoculture (C-C-C) and soybean or faba bean grown 2 years before corn (S-C-C and F-C-C, respectively), generally had similar effects on the stover and ear N uptake at both locations (Tables 1 and 5; Figs 3 and 4). At St-Anselme, the stover, ear and whole-plant N uptake for the F-C-C crop sequence were higher at 0 and 100 kg N ha^{-1} than in monoculture; at Deschambault similar trends were observed at 100 kg N ha^{-1} for the stover, ear and whole-plant N uptake, but were less pronounced than at St-Anselme (Figs. 3 and 4).

With 2 consecutive years of faba bean (F-F-C) as previous crop sequence, the corn

Table 4. N concentrations of forage corn as influenced by N rates and previous crops at St-Anselme and Deschambault in 1989

Crop sequences		St-Anselme			Deschambault		
		Stover	Ears	Whole plants	Stover	Ears	Whole plants
		(%)					
C[z]-C-C	0 N	0.59	1.12	0.82	0.69	1.14	0.94
	50 N	0.76	1.14	0.95	0.75	1.25	1.04
	100 N	0.86	1.12	1.03	0.73	1.17	1.03
	150 N	1.04	1.27	1.15	0.96	1.33	1.18
S[y]-C-C	0 N	0.59	1.13	0.85	0.59	1.18	0.91
	50 N	0.83	1.17	0.99	0.72	1.07	0.93
	100 N	0.94	1.26	1.11	0.82	1.16	1.01
	150 N	1.04	1.27	1.16	0.93	1.21	1.10
S-S-C	0 N	0.69	1.12	0.90	0.61	1.11	0.89
	50 N	0.85	1.20	1.03	0.72	1.23	1.07
	100 N	1.05	1.27	1.16	0.86	1.21	1.06
	150 N	1.06	1.24	1.15	0.94	1.20	1.13
F[x]-C-C	0 N	0.69	1.16	0.92	0.70	1.19	0.98
	50 N	0.81	1.12	0.97	0.67	1.22	0.99
	100 N	1.01	1.28	1.15	0.80	1.26	1.09
	150 N	0.97	1.30	1.12	0.92	1.25	1.11
F-F-C	0 N	0.95	1.26	1.10	0.75	1.26	1.06
	50 N	0.96	1.39	1.18	0.83	1.18	1.05
	100 N	1.05	1.38	1.23	0.90	1.21	1.08
	150 N	1.09	1.39	1.26	0.96	1.30	1.16
Standard error		0.08	0.06	0.07	0.06	0.05	0.05

[z] Corn.
[y] Soybean.
[x] Faba bean.

stover, ear and whole-plant N uptake were generally higher than those of corn grown in monoculture at both locations ((C vs. 2F), Table 1; Figs. 3 and 4). In fact, at St-Anselme, the corn stover, ear and whole-plant N uptake were generally higher than those of the monoculture at all N levels, except for stover at 150 kg N ha^{-1} (Fig. 3). Similar results were obtained at Deschambault for the stover and whole-plant N uptake between 0 and 100 kg N ha^{-1}; the ear N uptake of corn from the F-F-C sequence was also higher than that of corn from the monoculture.

Two consecutive years of soybean (S-S-C) also had significant effects on corn N uptake compared with the monoculture (C vs. 2S, Table 1; Figs. 3 and 4). At both sites, the stover, ear and whole-plant N uptake were generally higher than those of corn from the C-C-C sequence when 0, 50 or 100 kg ha^{-1} were applied; exceptions were observed at both sites for stover N uptake at 150 kg N ha^{-1}.

In general, the N uptake of the stover, ears and whole plants increased with the N application at both locations, and the extent of the response was significantly different among the previous crop sequences (Tables 1 and 5; Figs. 3 and 4). The responses to N fertilization of corn for the S-C-C, S-S-C and the F-C-C crop sequences were similar to those of corn for the C-C-C crop sequence (Table 1; Figs. 3 and 4). On the other hand, the response to N fertilization of corn for the F-F-C crop sequence was less than that of corn for the monoculture ((C vs. 2F) × N_L significant, Table 1; Figs. 3 and 4). After 2 consecutive

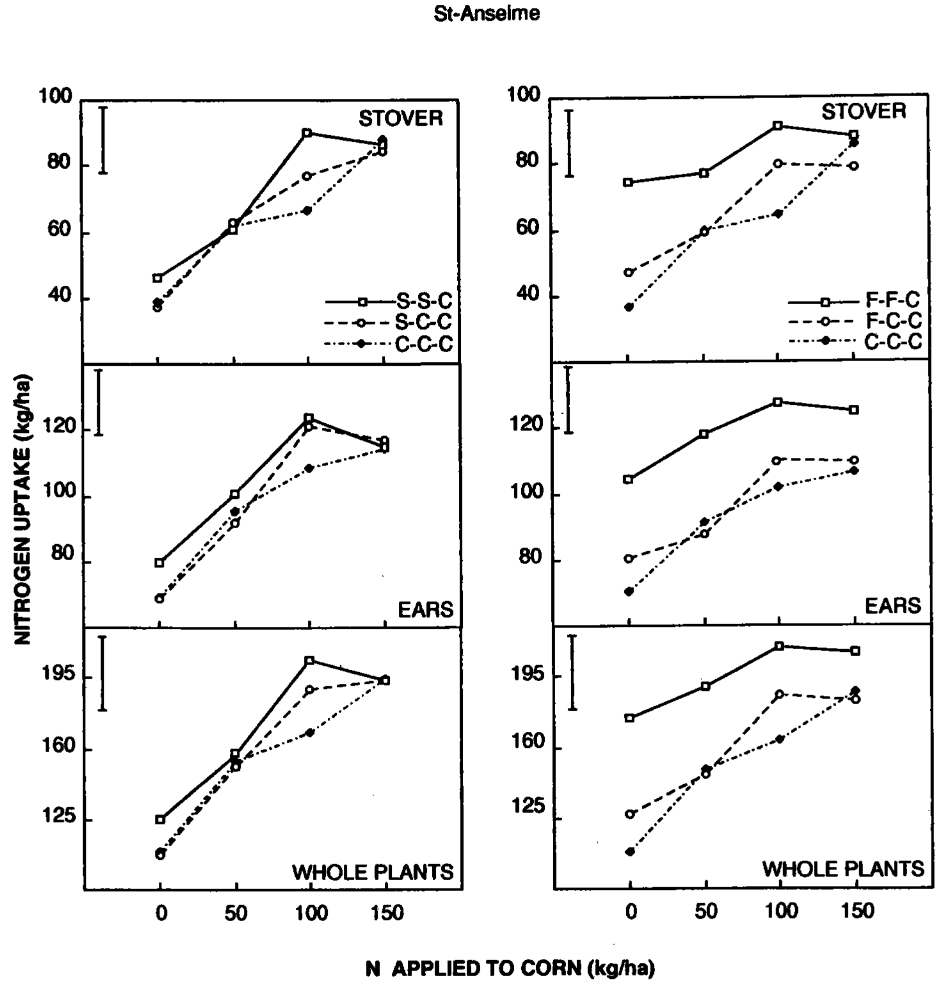

Fig. 3. N uptake of forage corn after 2 consecutive years of faba bean (F-F-C) and soybean (S-S-C), after faba bean (F-C-C) and soybean (S-C-C) grown 2 years previously and in monoculture (C-C-C) at St-Anselme. Vertical bars represent 2 standard errors of mean (n = 48).

years of soybean, the response to N fertilization of corn increased with the N application, and generally levelled off at 100 kg N ha^{-1}, while for corn grown in monoculture, the N uptake tended to increase up to 150 kg N ha^{-1} (Table 1; Figs 3 and 4). These differences were significant for the N uptake of the stover and whole plants, but not for the ear N uptake ((C vs. 2S) × N_Q, Table 1; Figs. 3 and 4).

N-fertilizer Replacement Values

At St-Anselme, on a DMY basis, the NFRV of 2 consecutive years of faba bean were 125, 60 and 65 kg N ha^{-1} for stover, ears and whole plants, respectively (Table 6) while at Deschambault, these values were 110,100 and 106 kg N ha^{-1}. The NFRV (DMY basis) of 2 consecutive years of soybean were 6, 24 and 12 kg N ha^{-1} for stover, ears and whole plants, respectively, at St-Anselme and, at

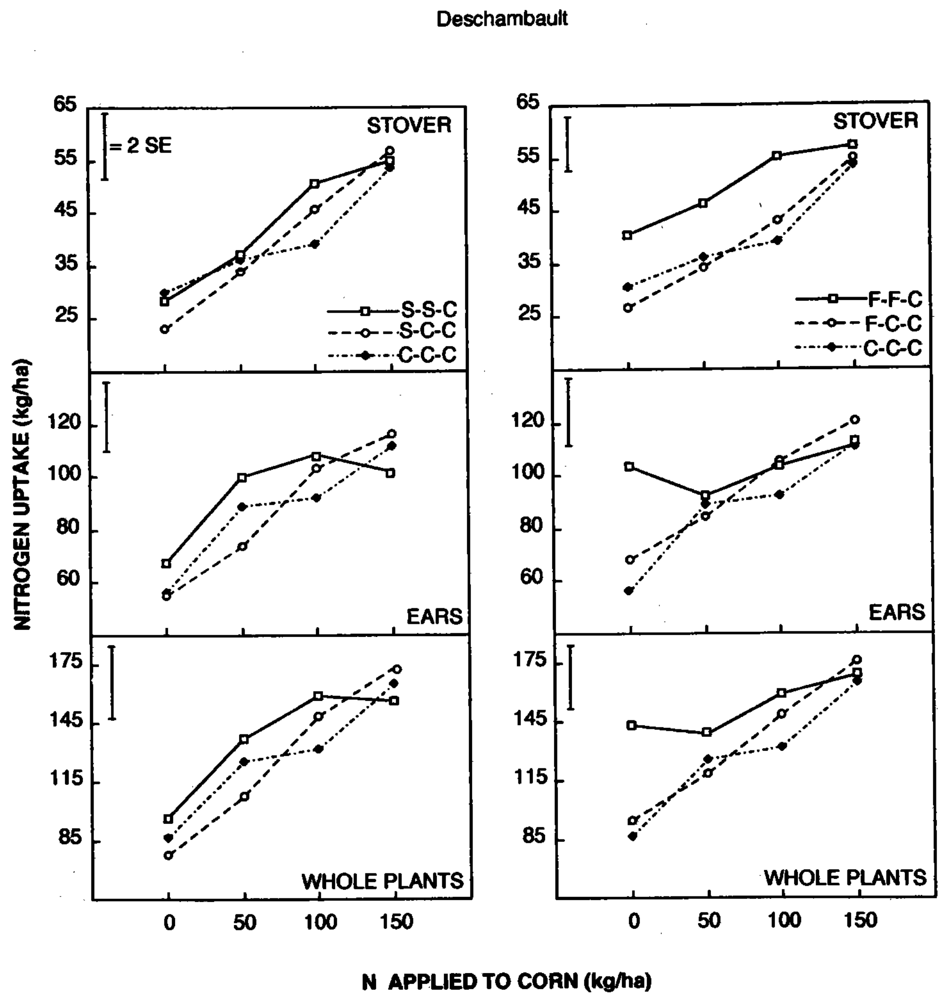

Fig. 4. N uptake of forage corn after 2 consecutive years of faba bean (F-F-C) and soybean (S-S-C), after faba bean (F-C-C) and soybean (S-C-C) grown 2 years previously and in monoculture (C-C-C) at Deschambault. Vertical bars represent 2 standard errors of mean (n = 48).

Deschambault, these values wer 40, 24 and 34 kg N ha^{-1}. At both locations, the NFRV of soybean grown 2 years previously were lower than 0 kg N ha^{-1} for the stover, ear and whole-plant DMY, except for the stover DMY at Deschambault, where it reached 4 kg N ha^{-1} (Table 6). At St-Anselme, the NFRV of faba bean grown 2 years previously were nearly equivalent (between 15 and 18 kg N ha^{-1}) for all plant fractions, while at Deschambault, they were lower than 0 kg N ha^{-1} for stover DMY, but were 16 and 12 kg N ha^{-1} for the ear and whole-plant DMY, respectively (Table 6). At both locations, the NFRV (N uptake basis) of soybean grown 2 years previously were lower or equal to 0 kg N ha^{-1} (Table 6). Those of 2 consecutive years of faba bean were 122, 129 and 126 kg N ha^{-1} at St-Anselme for stover, ears and whole plants, respectively, while these values were 104, 131 and 115 kg ha^{-1} at Deschambault for stover, ears and whole plants, respectively (Table 6). The NFRV of

Table 5. Regression equations for forage-corn N uptake (Y) as a function of N rates (N) for crop sequences at St-Anselme and Deschambault in 1989

Crop sequences	Plant fraction	Equations	$Pr>F$	R^2
		St-Anselme		
C[z]-C-C	Stover	$Y = 40.94 + 0.30\,N$	0.0001	0.76
	Ears	$Y = 74.74 + 0.24\,N$	0.0001	0.65
	Whole plants	$Y = 115.68 + 0.54\,N$	0.0001	0.78
S[y]-C-C	Stover	$Y = 41.95 + 0.31\,N$	0.0001	0.84
	Ears	$Y = 37.36 + 0.59\,N - 0.0018\,N^2$	0.0001	0.90
	Whole plants	$Y = 105.35 + 1.20\,N - 0.004\,N^2$	0.0001	0.91
S-S-C	Stover	$Y = 43.84 + 0.57\,N - 0.002\,N^2$	0.0002	0.74
	Ears	$Y = 77.38 + 0.57\,N - 0.002\,N^2$	0.0001	0.77
	Whole plants	$Y = 121.22 + 1.14\,N - 0.004\,N^2$	0.0001	0.81
F[x]-C-C	Stover	$Y = 51.05 + 0.23\,N$	0.0001	0.72
	Ears	$Y = 80.23 + 0.22\,N$	0.0001	0.71
	Whole plants	$Y = 132.19 + 0.45\,N$	0.0001	0.80
F-F-C	Stover	$Y = 76.29 + 0.11\,N$	0.030	0.31
	Ears	$Y = 108.00 + 0.14\,N$	0.038	0.27
	Whole plants	$Y = 183.91 + 0.24\,N$	0.008	0.43
		Deschambault		
C-C-C	Stover	$Y = 28.78 + 0.15\,N$	0.002	0.51
	Ears	$Y = 61.99 + 0.34\,N$	0.0001	0.82
	Whole plants	$Y = 90.78 + 0.48\,N$	0.0001	0.84
S-C-C	Stover	$Y = 23.02 + 0.23\,N$	0.0001	0.68
	Ears	$Y = 54.85 + 0.43\,N$	0.0001	0.70
	Whole plants	$Y = 77.86 + 0.65\,N$	0.0001	0.72
S-S-C	Stover	$Y = 28.92 + 0.18\,N$	0.0001	0.66
	Ears	$Y = 68.21 + 0.80\,N - 0.04\,N^2$	0.0001	0.78
	Whole plants	$Y = 106.83 + 0.41\,N$	0.0003	0.62
F-C-C	Stover	$Y = 25.71 + 0.19\,N$	0.0001	0.76
	Ears	$Y = 67.80 + 0.36\,N$	0.0008	0.56
	Whole plants	$Y = 93.51 + 0.54\,N$	0.0001	0.65
F-F-C	Stover	$Y = 40.90 + 0.12\,N$	0.0005	0.59
	Ears	$Y = 97.21 + 0.35\,N$	0.35	0.06
	Whole plants	$Y = 138.12 + 0.19\,N$	0.063	0.22

[z] Corn.
[y] Soybean.
[x] Faba bean.

2 consecutive years of soybean and of faba bean grown 2 years previously were very similar for both crop sequences, and slightly higher at St-Anselme than at Deschambault (Table 6). In fact, they were negative only for stover at Deschambault.

DISCUSSION

At both locations, corn yielded more DM and took up more N following 2 consecutive years of faba bean than in other crop sequences. In addition, there was no response to N application following 2 consecutive years of faba bean.

Table 6. N-fertilizer replacement values (NFRV) of legumes in forage-corn production as estimated by N fertilizer response functions at St-Anselme and Deschambault in 1989

Cropping system	N-fertilizer replacement values (kg N ha^{-1})											
	Dry-matter yield basis						N uptake basis					
	St-Anselme			Deschambault			St-Anselme			Deschambault		
	Stover	Ears	WP[z]	Stover	Ears	WP	Stover	Ears	WP	Stover	Ears	WP
S[y]-C-C[x]	<0	<0	<0	4	<0	<0	0	0	0	<0	0	<0
S-S-C	6	24	12	40	24	34	14	21	15	<0	15	10
F[w]-C-C	15	18	17	<0	16	12	22	24	25	<0	15	8
F-F-C	125	60	65	110	100	106	122	129	126	104	131	115

[z] Whole plants.
[y] Soybean.
[x] Corn.
[w] Faba bean.

Two consecutive years of soybean had much less impact on subsequent corn yields obtained at 0 kg N ha^{-1}. These differences can be explained partly by the impact of the second year of legume cultivation on the soil N balance. In a parallel study at both locations (Chalifour et al. unpublished), it was determined by ^{15}N isotope dilution (Rennie and Rennie 1983) that the amounts of N derived from the atmosphere (Ndfa) by faba bean were 169 kg N ha^{-1} on average at both sites, with an average of 71% Ndfa. Soybean fixed 154 kg N ha^{-1} on average, with an average of 63.5% Ndfa. However, when taking N balances into consideration (Beck et al. 1991), faba bean cultivation in 1988 (i.e., second year of legume cultivation) led to positive N balances at both sites, i.e., 61 kg N ha^{-1} at Deschambault and 148 kg N ha^{-1} at St-Anselme; it was particularly high at St-Anselme, due to drought which reduced grain yield very significantly (1218 kg ha^{-1} at St-Anselme compared to 3033 kg ha^{-1} at Deschambault). Soybean cultivation in 1988 led to a negative (−18 kg N ha^{-1}) soil N balance at Deschambault and to a slightly positive (7 kg N ha^{-1}) soil N balance at St-Anselme; this difference can be attributed to the fact that more grains were harvested at Deschambault (3473 kg ha^{-1}), compared to St-Anselme (2715 kg ha^{-1}), suggesting differences in quantities of N exported in seeds. In the first year of legume production (i.e., 1987) faba bean cultivation led to positive N balances at both sites (51 kg N ha^{-1} at Deschambault and 41 kg N ha^{-1} at St-Anselme), while soybean led to similar negative soil N balances at both sites (−69 kg N ha^{-1}) (Paré et al. 1992); at the same time 2447 and 3924 kg ha^{-1} of faba bean grains and 2914 and 3072 kg ha^{-1} of soybean grains were harvested at St-Anselme and Deschambault, respectively.

The residual effects of faba bean grown 2 years previously (F-C-C) on corn yields and N uptake compared well with those observed in previous studies. Senaratne and Hardarson (1988) reported benefits of legumes (faba bean and pea) compared with barley as previous crops in a second succeeding barley crop production. Wright (1990) also reported greater productivity and N uptake of wheat as a second subsequent crop on plots where faba bean and pea grew 2 years previously than on those cropped with lentil or barley, but he could not attribute them only to the N contribution of these pulses. In our study, the higher DMY and N uptake obtained with the F-C-C sequence at 0 kg N ha^{-1} compared with monoculture at both sites, suggest that substantial amounts of N can likely be available for a second subsequent corn crop from legume residues. However, Ladd et al. (1983) reported that only 4.8% of the ^{15}N was available for a second wheat crop maturing within 25 mo of labelled medic

(*Medicago littoralis*) incorporation. Furthermore, Harris and Hesterman (1990) found that only 1% of the original alfalfa-N input was recovered by a second subsequent barley crop at two field locations in Michigan. These two studies suggest that the recovery of the remaining N from legume residues by second succeeding non-legume crops are estimated by the recovery of N from ^{15}N-labelled legume residues may be less than the contributions estimated by other methods. The differences observed with the F-C-C sequence at 0 kg N ha^{-1} compared with the monoculture may also be related to the soil N conserved in the year of legume production. The results of Ladd et al. (1983) and of Harris and Hesterman (1990) would be consistent with this interpretation. Our study showed that faba bean grown 2 years previously had no effect on forage corn N concentration; this agrees with the results of Wright (1990) who did not find any increase in wheat protein content due to pea or faba bean grown 2 years earlier. Soybean grown 2 years previously did not enhance the DMY and N concentration and uptake of corn grown with 0 kg N ha^{-1}; this provides additional evidence that this legume was less effective under the present experimental conditions than faba bean in reducing N requirements for forage corn as first (Paré et al. 1992) or second (this study) subsequent crop. However, with the S-C-C sequence, the corn stover, ear and whole-plant DMY obtained at the highest N level (i.e., 150 kg N ha^{-1}) where higher than those of corn grown in monoculture at Deschambault; this corresponds to the rotation effect, as defined by Baldock et al. (1981), which was also observed for the F-C-C sequence at the same time. For other crop sequences (i.e., S-S-C and F-F-C at both sites), corn generally reached maximum DMY at 100 kg N ha^{-1}, and DMY decreased at the highest N level. Thus, there were clear rotation effects at the N level where maximum DMY were obtained, which was not always the case at the highest N level. Due to the impact of previous crops and N levels on tissue N concentration, estimates of N-rotation effects on a DMY basis would be different from those on a N uptake basis (Figs. 1-4). This should be taken into consideration when emphasis is put on the impact of N_2-fixing legumes on N nutrition of subsequent non-fixing crops.

At Deschambault, except for stover, the NFRV (DMY basis) for 2 consecutive years of faba bean were higher than at St-Anselme; however, when expressed on a N uptake basis, the NFRV for the same previous crop sequence were almost equivalent at both locations. This is due to the fact that there were greater differences in ear and whole-plant N concentrations between the F-F-C and C-C-C sequences at St-Anselme than there were at Deschambault (Table 4; Figs. 1-4). In addition, for the St-Anselme site, the NFRV (DMY and N uptake basis) of 2 consecutive years of faba bean were lower than the 150 kg N ha^{-1} obtained with 1 year of this pulse (Paré et al. 1992); in contrast, for the Deschambault location, the NFRV (DMY and N uptake basis) for 2 consecutive years of faba bean outyielded those reported for 1 year of this legume (Paré et al. 1992). Few data have been published on NFRV for legumes followed by a second succeeding non-legume crop; Fox and Piekielek (1989) reported fertilizer N equivalence values of 39, 52 and 32 kg N ha^{-1} for alfalfa (*Medicago sativa* L.), birdsfoot trefoil (*Lotus corniculatus* L.) and red clover (*Trifolium pratense* L.), respectively, for corn produced in the second year. In the same study, the authors measured the fertilizer N equivalence values of about 146, 102 and 116 kg N ha^{-1} for alfalfa and birdsfoot trefoil (grown 3 consecutive years) and for red clover (grown 2 consecutive years), respectively, in the first year of corn production. These values are higher than those obtained in our study for faba bean grown for 2 consecutive years, and may be due in part to the fact that these forage legumes leave more N in the soil by the mineralization of the N in their crowns and roots (Heichel and Barnes 1984) compared to residues of annual pulses (Brunner and Zapata 1984; Zapata et al. 1987a) and may also contribute more to soil N conservation. The NFRVs reported by other investigators for a number of legumes are mostly based on DM production. When the tissue N concentrations are taken into account, however, thereby considering the real impact of previous legume on the N nutrition of a non-fixing crop, NFRV estimates based on N uptake can be quite different from those based on DMY (Tables 4 and 6; Figs. 1–4); the data obtained in the present study indicate that DMY-based NFRVs can either underestimate (i.e., F-F-C sequence at St-Anselme) or overestimate (i.e., S-S-C sequence at Dechambault) the impact of previous legume on the N nutrition of corn.

In Quebec, the N rate recommended for corn grown for grain or forage varies between 165 (CPVQ 1984) and 180 kg ha^{-1} (AFEQ 1990). However, given the fact that early-maturing hybrids generally have a lower-yielding potential than hybrids later in maturity, the highest N rate was adjusted to 150 kg N ha^{-1} in this experiment. With corn hybrid Pioneer 3979, generally the whole-plant DMY reached a maximum at ca. 100 kg N ha^{-1} at St-Anselme, and at ca. 150 kg N ha^{-1} at Deschambault in monoculture. The results indicated also that N fertilization would not have been necessary for corn following 2 consecutive years of faba bean; indeed, the DMY of corn from the F-F-C sequence were either equivalent or substantially higher than those of corn grown in monoculture which received 150 kg N ha^{-1}. Following faba bean grown 2 years previously (F-C-C sequence), a reduction in N fertilizer application of ca. 15–20 kg N ha^{-1} at St-Anselme would have been appropriate; thus, an application of about 90 kg N ha^{-1} would seem adequate for a second corn crop (Figs. 1 and 3). At Deschambault, the reduction in N application following faba bean grown 2 years previously could be 10 kg N ha^{-1}; however, based on the DMY and N uptake data, N application could be reduced substantially more than suggested by NFRV estimates, to reach DMY and N uptake values similar to those obtained in monoculture, i.e., by about 30 kg N ha^{-1}; this would mean a N level of 120 kg N ha^{-1}. At St-Anselme, the reduction in N fertilization following two consecutive years of soybean could be about 10–15 kg N ha^{-1}; a N fertilizer application of ca. 90 kg N ha^{-1} would thus seem appropriate; at Deschambault, for the same crop sequence, a reduction of about 30 kg N ha^{-1} in fertilization would bring the N required to 120 kg N ha^{-1}.

CONCLUSION

Faba bean grown for 2 consecutive years provided more benefit (i.e., greater N contribution) to a following corn crop than soybean grown previously for 2 consecutive years. This can be related in part to positive soil N balances in 1988 following faba bean cultivation at both sites, and to slightly negative and slightly positive balances for soybean at Deschambault and St-Anselme, respectively. The corn yield data obtained at St-Anselme following 2 consecutive years of faba bean do not indicate greater total rotation effects compared with corn yields obtained after 1 year of faba bean cultivation (this study and Paré et al. (1992)). This contrasts with the data obtained at Deschambault, which showed that 2 years of faba bean cultivation were necessary to obtain elevated NFRVs which could replace most of the N requirements of the corn crop (this study and Paré et al. (1992)). Dinitrogen fixation in soybean in the second year was greater than in the first year; this was related to improved soil N balances, which certainly contributed to the rotation effects obtained with this legume at 0 kg N ha^{-1}, not observed after 1 year of cultivation of this legume (this study and Paré et al. (1992)). Rotation effects observed at the intermediate N levels for the S-S-C, F-C-C and F-F-C crop sequences must imply additional mechanisms to N supply or conservation, which could explain the growth promoting effects of legumes. Further research is needed to investigate these mechanisms and their levels of implication.

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