# Residual effects of faba bean and soybean for a second or third succeeding forage-corn production

Théophile Paré[1], François-P. Chalifour[1,3], Josée Bourassa[1], and Hani Antoun[2]

[1]*Département de Phytologie et* [2]*Département des sols, Faculté des Sciences de l'Agriculture et de l'Alimentation, Université Laval, Sainte-Foy, Québec, Canada G1K 7P4.* *Received 22 April 1992, accepted 30 November 1992.*

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Paré, T., Chalifour, F.-P., Bourassa, J. and Antoun. H. 1993. **Residual effects of faba bean and soybean for a second or third succeeding forage-corn production.** Can. J. Plant Sci. **73**: 495–507. Many studies have been conducted on the effects of annual legumes on subsequent corn production but they rarely extended beyond a second succeeding crop. We have therefore conducted field experiments on a sandy gravelly loam at St-Anselme and on a silty loam at Deschambault in eastern Quebec to determine the residual effects of (i) faba bean (*Vicia faba* L.) and soybean (*Glycine max* [L.] Merr.) on a third succeeding corn (*Zea mays* L.) crop and (ii) 2 consecutive years of these legumes on a second subsequent corn crop. In monoculture or following legumes, corn was fertilized with 0, 50, 100 or 150 kg N ha$^{-1}$ as $NH_4NO_3$. The corn stover and whole-plant dry matter yields (DMY), and the ear and whole-plant N uptake were higher following faba bean grown 3 years earlier than in monoculture at both locations. At Deschambault, the stover DMY of second subsequent corn following 2 consecutive years of faba bean did not vary with the N application. At both locations, the DMY, N concentrations and N uptake of second subsequent corn were higher after 2 consecutive years of faba bean than after other previous crop sequences. Two consecutive years of soybean had significant effects on the DMY and N uptake of a second subsequent corn crop with N application at Deschambault. At both locations, the N-fertilizer replacement values (NFRV) of soybean were lower or equal to 0 kg N ha$^{-1}$. The NFRV (DMY and N uptake bases) of faba bean grown three years earlier and of 2 consecutive years of this pulse varied widely between locations.

Key words: Corn, faba bean, soybean, residual N, crop sequence, rotation effects

Paré, T., Chalifour, F.-P., Bourassa, J. et Antoun, H. 1993. **Effets résiduels du soja et de la féverole pour la production d'une seconde ou troisième culture subséquente de maïs-fourrage.** Can. J. Plant Sci. **73**: 495–507. Beaucoup de recherches ont été menées sur les effets de légumineuses annuelles sur la production d'une culture subséquente de maïs, mais rarement au delà de la seconde culture subséquente. Par conséquent, afin d'obtenir davantage de données pertinentes nous avons mené des expériences au champ sur un loam sablo-graveleux à St-Anselme et sur un loam argileux à Deschambault dans l'est du Québec, pour déterminer les effets résiduels de (i) la féverole (*Vicia faba* L.) et du soja (*Glycine max* [L.] Merr.) sur la production d'une troisième culture subséquente de maïs (*Zea mays* L.) et (ii) de deux années consécutives de ces légumineuses sur la production d'une seconde culture subséquente de maïs. En monoculture ou subséquent à des légumineuses, le maïs a été fertilisé avec 0, 50, 100 ou 150 kg N ha$^{-1}$ sous forme de $NH_4NO_3$. Les rendements en matière sèche (RMS) des cannes et des plantes entières, de même que l'absorption d'N du maïs étaient supérieurs après la féverole cultivée trois années auparavant qu'en monoculture et cela aux deux sites. À Deschambault, après deux années consécutives de féverole, le RMS des cannes de la deuxième culture subséquente de maïs n'ont pas été influencés par l'application d'N. Aux deux sites, les RMS, les concentrations et l'absorption d'N du maïs étaient supérieurs subséquemment à deux années consécutives de féverole comparativement aux autres séquences culturales précédentes. Deux années consécutives de soja ont eu des effets significatifs sur les RMS et l'absorption d'N de la deuxième culture subséquente de maïs avec l'application d'N à Deschambault. Les valeurs de remplacement en fertilisants azotés (VRFA) des séquences

[3]To whom correspondence should be addressed.

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impliquant le soya étaient inférieures ou égales à 0 kg N $ha^{-1}$ aux deux sites. Les VRFA (basées sur les RMS ou l'absorption d'N) pour la féverole cultivée trois années auparavant et celles de deux années consécutives de cette légumineuse ont beaucoup varié d'un site à l'autre.

Mots clés: Maïs, féverole, soja, N résiduel, séquence culturale, effets de rotation

Recent research in eastern Quebec has shown that the N requirement of forage corn can be fulfilled in part or totally when it follows faba bean grown for grain for 1 or 2 consecutive yrs (Paré et al. 1992, 1993). However, we have noted lesser effects to succeeding corn DM production and N uptake from soybean grown 1 yr previously than from 2 consecutive years (Paré et al, 1992, 1993). It has been also shown that faba bean can partly meet the N needs of a second succeeding forage corn crop when compared to soybean (Paré et al. 1993). Previously, Senaratne and Hardarson (1988) observed appreciable yield increases of subsequent barley (*Hordeum vulgare* L.) and sorghum (*Sorghum vulgare* L.) crops following faba bean and pea (*Pisum sativum* L.) compared with continuous barley. In Western Canada, Wright (1990) reported that faba been, field pea and lentil (*Lens culinaris* Medic.) increased subsequent cereal yields, on average, by 21% in the first year and by 12% in the second year of production.

There have been few studies on the effects of legumes (annual or perennial) on the N nutrition of third subsequent non-legume crops. Fox and Piekielek (1988), in a field experiment conducted in Pennsylvania, reported beneficial effects of alfalfa (*Medicago sativa* L.), birdsfoot trefoil (*Lotus corniculatus* L.) and red clover (*Trifolium pratense* L.) on a third succeeding corn production. The fact that these forage legumes grew continuously during 2 (red clover) and 3 (alfalfa and birdsfoot trefoil) years, and that they generally leave significant amounts of N in the soil by the mineralization of organic N in their crowns and roots (Heichel and Barnes 1984), could explain the yield increases of a third subsequent corn crop. Hitherto, few studies have been published on the impact of 2 consecutive years of annual legumes on second succeeding corn yields. The objective of our study was to determine (i) the effects of 1 yr of faba bean and soybean production on a third subsequent forage corn crop, and (ii) the effects of 2 yr of faba bean and soybean production on a second subsequent forage corn crop.

## MATERIALS AND METHODS

Crop rotation trials were conducted from 1987 to 1990 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, herbicides and N application and other cultural practices from 1987 to 1989 growing seasons were described previously by Paré et al. (1992, 1993).

The results reported here are for the 1990 growing season, i.e., the fourth year of the following crop sequences: (i) continuous corn (C–C–C–C); (ii) soybean-corn-corn-corn (S–C–C–C); (iii) soybean-soybean-corn-corn (S–S–C–C); (iv) faba bean-corn-corn-corn (F–C–C–C); and (v) faba bean-faba bean-corn-corn (F–F–C–C). Corn in each of these crop sequences received 0, 50, 100 or 150 kg N $ha^{-1}$ as $NH_4NO_3$ applied as described previously (Paré et al. 1992). Thus, the experimental design consisted of 20 treatments arranged in a randomized complete block replicated four times at each location. Total precipitation (April to October) for the growing season was 806 and 586 mm at St-Anselme and Deschambault, respectively; corn heat units (CHUs) (2824 and 2685 at St-Anselme and Deschambault, respectively) were above normal. Before planting in 1990, 28.0 kg $ha^{-1}$ of P and 159.4 kg $ha^{-1}$ of K as 0–10–30 were applied at St-Anselme, while at Deschambault, 62.5 kg $ha^{-1}$ of P and 118.7 kg $ha^{-1}$ of K were applied as 0–26–26, and incorporated by discing at both locations. Pre-emergence herbicides ((atrazine (1.5 kg a.i. $ha^{-1}$) and metolachlor (1.8 kg a.i. $ha^{-1}$)) were used for corn at both locations.

Three central rows of each corn plot were harvested with a forage harvester after the ears were removed by hand, to evaluate the dry-matter yields (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. Total N concentration was determined on the ground samples after Kjeldahl digestion using a Technicon autoanalyzer (Technicon 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 in SAS (Statistical Analysis System Institute Inc. 1990). 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 AND DISCUSSION

### Dry Matter Yields of Forage Corn

Averaged across both locations, the forage-corn stover and whole-plant DMY were higher for the F–C–C–C crop sequence than for corn grown in monoculture (C–C–C–C) (Table 1; Figs. 1 and 2). Continuous corn produced less stover and whole-plant DMY than corn following faba bean grown 3 yr previously at 0, 50 and 100 kg N $ha^{-1}$ at St-Anselme. At Deschambault, the corn ear and whole-plant DMY for the F–C–C–C sequence were greater with the application of 100 and 150 kg N $ha^{-1}$ than for corn grown in monoculture and receiving the same amounts of N (Fig. 2). These results agree with those of Fox and Piekielek (1988) who observed in the third year following birdsfoot trefoil and red clover cultivation, significant grain yield increases of subsequent corn compared with continuous corn at low rates of N (0, 50 and 100 kg N $ha^{-1}$). Furthermore, there were slight N-rotation effects observed at 0 kg N $ha^{-1}$ 3 yr after faba bean production (Figs. 1 and 2; Table 6) presumably due to the positive N balance obtained at both locations with this legume cultivation in 1987 (Paré et al. 1992).

At both locations, and particularly at Deschambault, the DMY of forage corn as second subsequent crop to 2 consecutive years of faba bean (F–F–C–C) were generally higher than those in monoculture (Table 1; Figs. 1 and 2) and were likely due in part to the persisting availability of this legume residual N and/or to the N conservation effect of faba bean (Paré et al. 1992, 1993). Corn monoculture (C–C–C–C) and 2 consecutive years of soybean and corn (S–S–C–C) as previous crops were significantly different for the ear and whole-plant DMY, especially at Deschambault at 50, 100 and 150 kg N $ha^{-1}$ (C vs. 2S, Table 1; Figs. 1 and 2). Rotation effects were observed with the S–S–C–C sequence for corn stover DMY when 100 and 150 kg N $ha^{-1}$ were applied (Fig. 2), and at all N levels (except at 0 kg N $ha^{-1}$) for ear and whole-plant DMY. This synergistic relationship between 2 consecutive years of soybean (S–S–C–C) and N fertilizer for corn stover, ear and whole-plant DMY at Deschambault appeared to be due to rotation effects other than N-rotation effects, because no differences were observed between corn from this crop sequence and monoculture at 0 kg N $ha^{-1}$ at both locations. In our study, rotation effects as defined by Baldock et al. (1981) were not necessarily observed at the highest N level. Indeed, they defined the total rotation effect as the yield differential without N application, the rotation effects as the yield

Table 1. Summary from the analyses of variance for forage corn dry-matter yields and N uptake at St-Anselme and Deschambault in 1990

| | | Dry-matter yields | | | N uptake | | |
|---|---|---|---|---|---|---|---|
| Source of variation | df | Stover | Ears | Whole plants | Stover | Ears | Whole plants |
| | | (Mean squares) | | | | | |
| Locations (L) | 1 | (33.1) | (0.9) | (22.9) | (5 511.2) | (795.0) | (2 059.3) |
| Rep[z](within) L | 6 | 1.4 | 2.3 | 5.1 | 243.8 | 450.1 | 877.5 |
| Previous crops (PC) | 4 | 1.4*** | 2.1*** | 6.4*** | 222.4** | 707.8*** | 1 533.4*** |
| C[y] vs. S[x] | 1 | 0.1 | 0.2 | 0.0 | 75.5 | 143.3 | 10.7 |
| C vs. F[w] | 1 | 1.3* | 0.6 | 3.8* | 180.3 | 436.7* | 1 205.0** |
| C vs. 2 S[v] | 1 | 1.0 | 2.7* | 7** | 129.1 | 787.2** | 1 555** |
| C vs. 2 F[u] | 1 | 2.9* | 6.7*** | 18.4*** | 272.6* | 2 519*** | 4 447*** |
| Nitrogen (N) | 3 | 19.5*** | 92.3*** | 195.8*** | 9 312*** | 20 709*** | 57 344*** |
| $N_L$[t] | 1 | 53.7*** | 246.2*** | 530*** | 27 855*** | 58 912*** | 167 789*** |
| $N_Q$[s] | 1 | 4.1*** | 30.6*** | 57*** | 81.9 | 3 157.8*** | 4 296*** |
| L × PC | 4 | 0.7 | 0.4 | 1.5 | 130.5 | 92.3 | 210.7 |
| L × (C vs. S) | 1 | 1.4* | 0.2 | 0.4 | 443.3* | 21.5 | 269.5 |
| L × (C vs. F) | 1 | 0.3 | 0.3 | 0.0 | 151.9 | 203.6 | 2.4 |
| L × (C vs. 2 S) | 1 | 0.0 | 1.3 | 1.8 | 16.6 | 262.1 | 146.6 |
| L × (C vs. 2 F) | 1 | 0.0 | 1.0 | 1.5 | 89.3 | 126.5 | 3.2 |
| L × N | 3 | 0.2 | 2.1** | 1.0 | 24.8 | 360.3 | 248.6 |
| L × $N_L$ | 1 | 0.4 | 4.4** | 2.0 | 71.8 | 763.3** | 373.0 |
| L × $N_Q$ | 1 | 0.0 | 0.0 | 0.0 | 1.4 | 5.8 | 2.5 |
| PC × N | 12 | 0.7* | 0.5 | 2.0** | 96.9 | 105.0 | 320.7* |
| (C vs. S) × $N_Q$ | 1 | 2.6** | 1.1 | 7.2** | 143.5 | 270.7 | 808.5* |
| (C vs. F) × $N_Q$ | 1 | 0.1 | 0.0 | 0.1 | 8.2 | 4.4 | 1.6 |
| (C vs. 2 S) × $N_Q$ | 1 | 1.2 | 0.2 | 2.5 | 219.2 | 115.3 | 652.4* |
| (C vs. 2 F) × $N_Q$ | 1 | 0.0 | 1.5 | 1.7 | 6.8 | 238.5 | 325.9 |
| L × PC × N | 12 | 0.3 | 0.8* | 1.8* | 47.8 | 151.0 | 213.5 |
| L × (C vs. S) × $N_L$ | 1 | 0.0 | 0.4 | 0.4 | 0.1 | 58.4 | 54.2 |
| L × (C vs. F) × $N_L$ | 1 | 0.3 | 2.7* | 4.7* | 1.0 | 223.3 | 188.2 |
| Error | 114 | 0.32 | 0.4 | 0.8 | 63.6 | 74.4 | 142.5 |
| CV (%) | | 8.2 | 10.3 | 6.6 | 14.4 | 10.5 | 8.5 |
| Total | 159 | | | | | | |

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

differential at the highest N level, and the N-rotation effect as the total rotation minus the rotation effect. In the experiments reported here and elsewhere (Paré et al. 1992, 1993), we consider the N level at which corn yields preceded by legumes are maximized, to determine rotation effects, instead of the maximum N level applied. The lack of significant N-rotation effects 2 yr after 2 consecutive years of soybean (S–S–C–C) may not be surprising due to the negative or only limited impact of soybean on the soil N balance (Paré et al. 1992, 1993).

The DMY generally increased significantly with N application at both locations and the degree of response varied among previous crop sequences ($N_L$, $N_Q$, PC × N; Tables 1 and 2; Figs. 1 and 2). However, at Deschambault, N application did not affect the stover DMY of corn as a second succeeding crop to

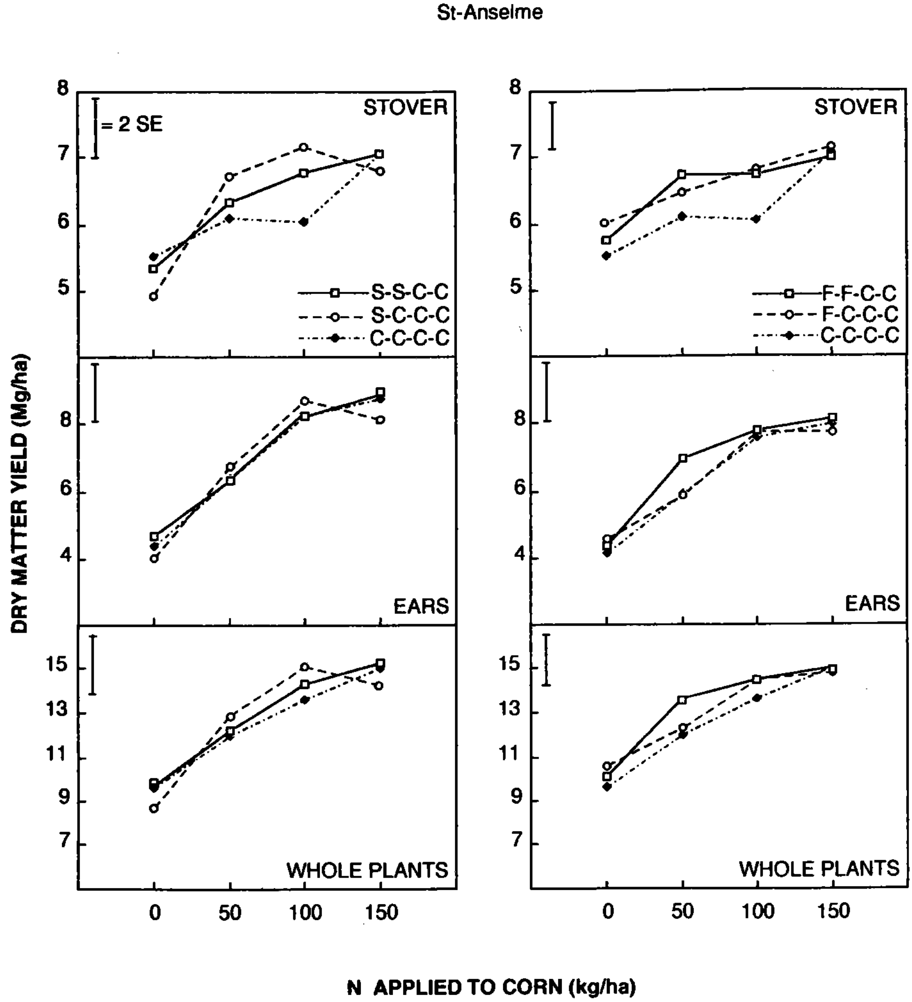


Fig. 1. Dry-matter yields of forage corn as second subsequent crop after 2 consecutive yr of faba bean (F–F–C–C) and soybean (S–S–C–C), after faba bean (F–C–C–C) and soybean (S–C–C–C) grown 3 yr previously and in monoculture (C–C–C–C) at St-Anselme. Vertical bars represent 2 standard errors of mean ($n$ = 48).

2 consecutive years of faba bean compared with corn grown in monoculture (Table 2; Fig. 2). There was a greater linear response to N application for ear DMY at St-Anselme than at Deschambault (L $\times$ $N_L$, Table 1; Figs. 1 and 2). Corn in monoculture or following faba bean grown 3 yr previously showed a similar linear response to N application at St-Anselme. At Deschambault, however, the DMY of corn following faba bean grown 3 yr previously responded more linearly to N application than the DMY of corn in monoculture (Fig. 2).

## N Concentration of Forage Corn

Previous crops (except the S–S–C–C sequence) had significant effects on the ear N concentrations, especially after 2 consecutive years of faba bean (Tables 3 and 4). Indeed, for the F–F–C–C crop sequence, the

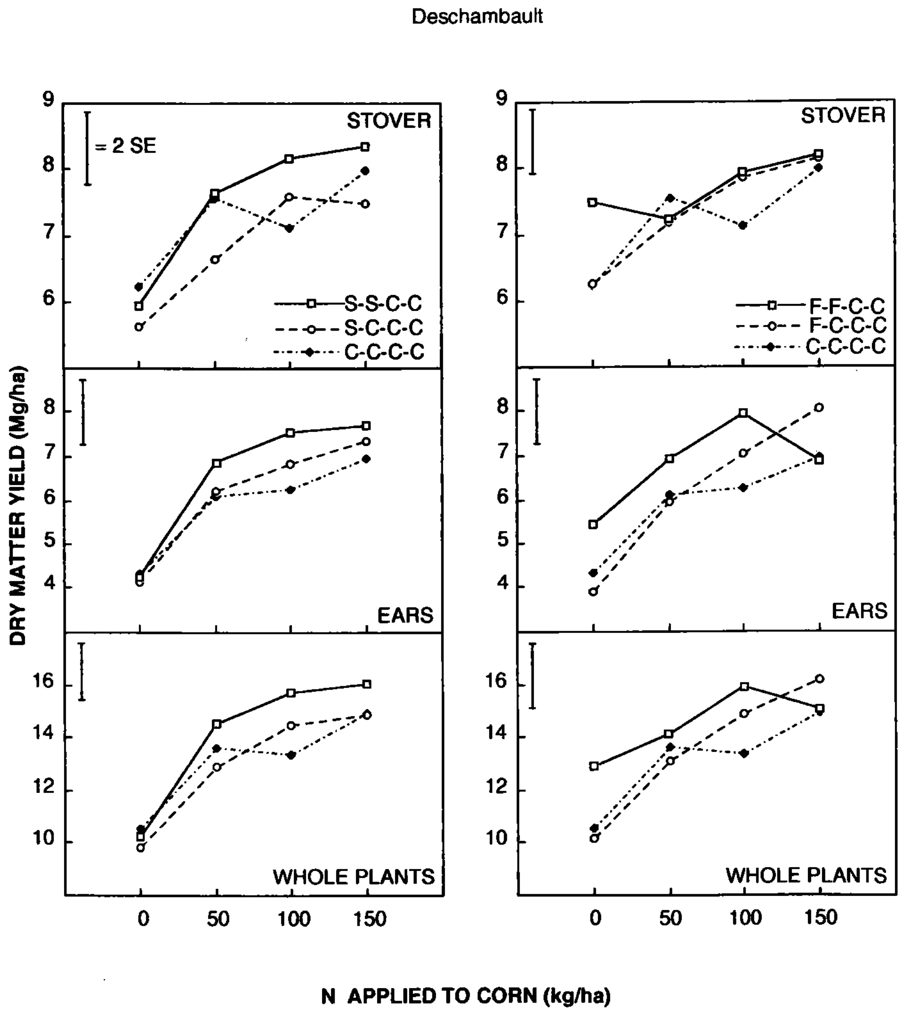


Fig. 2. Dry-matter yields of forage corn as second subsequent crop after 2 consecutive years of faba bean (F–F–C–C) and soybean (S–S–C–C), after faba bean (F–C–C–C) and soybean (S–C–C–C) grown 3 yr previously and in monoculture (C–C–C–C) at Deschambault. Vertical bars represent 2 standard errors of mean ($n$ = 48).

ear and whole-plant N concentrations were higher than those obtained for continuous corn for all N rates and locations, except with 150 kg N $ha^{-1}$ at Deschambault for the whole-plant N concentrations (Tables 3 and 4). This positive effect from 2 yr of faba bean production on the second subsequent corn N concentrations is consistent with the N-rotation effects observed with this crop sequence.

Following faba bean grown 3 yr earlier, the ear N concentrations were substantially higher than those of corn in monoculture at both locations, particularly at Deschambault (C vs. F; Tables 3 and 4). The previous crop effects on N concentrations varied between locations (Tables 3 and 4). At St-Anselme, following soybean and faba bean grown 3 yr previously, the stover N concentrations were generally

Table 2. Regression equations for forage corn dry-matter yields ($Y$) as a function of N rates ($N$) for crop sequences at St-Anselme and Deschambault in 1990

| Crop sequences | Plant fraction | Equations | Pr > F | $R^2$ |
|---|---|---|---|---|
| | | *St-Anselme* | | |
| C[z]-C-C-C | Stover | $Y = 5.48 + 0.009\,N$ | 0.0034 | 0.46 |
| | Ears | $Y = 4.37 + 0.026\,N$ | 0.0001 | 0.84 |
| | Whole plants | $Y = 9.86 + 0.035\,N$ | 0.0001 | 0.87 |
| S[y]-C-C-C | Stover | $Y = 4.95 + 0.044\,N - 0.0002\,N^2$ | 0.0004 | 0.69 |
| | Ears | $Y = 3.72 + 0.069\,N - 0.0003\,N^2$ | 0.0001 | 0.83 |
| | Whole plants | $Y = 8.67 + 0.11\,N - 0.0005\,N^2$ | 0.0001 | 0.87 |
| S-S-C-C | Stover | $Y = 5.53 + 0.011\,N$ | 0.0001 | 0.67 |
| | Ears | $Y = 4.52 + 0.026\,N$ | 0.0001 | 0.91 |
| | Whole plants | $Y = 10.06 + 0.04\,N$ | 0.0001 | 0.91 |
| F[w]-C-C-C | Stover | $Y = 6.06 + 0.007\,N$ | 0.0001 | 0.68 |
| | Ears | $Y = 4.72 + 0.023\,N$ | 0.0001 | 0.80 |
| | Whole plants | $Y = 10.77 + 0.03\,N$ | 0.0001 | 0.83 |
| F-F-C-C | Stover | $Y = 6.00 + 0.007\,N$ | 0.0037 | 0.46 |
| | Ears | $Y = 4.94 + 0.024\,N$ | 0.0001 | 0.65 |
| | Whole plants | $Y = 10.94 + 0.03\,N$ | 0.0001 | 0.65 |
| | | *Deschambault* | | |
| C-C-C-C | Stover | $Y = 6.48 + 0.009\,N$ | 0.0022 | 0.50 |
| | Ears | $Y = 4.70 + 0.016\,N$ | 0.0002 | 0.63 |
| | Whole plants | $Y = 11.19 + 0.026\,N$ | 0.0001 | 0.70 |
| S-C-C-C | Stover | $Y = 5.87 + 0.013\,N$ | 0.0013 | 0.53 |
| | Ears | $Y = 4.61 + 0.02\,N$ | 0.0002 | 0.63 |
| | Whole plants | $Y = 10.49 + 0.03\,N$ | 0.0001 | 0.67 |
| S-S-C-C | Stover | $Y = 6.35 + 0.01\,N$ | 0.0005 | 0.59 |
| | Ears | $Y = 4.96 + 0.02\,N$ | 0.0001 | 0.68 |
| | Whole plants | $Y = 11.31 + 0.04\,N$ | 0.0001 | 0.71 |
| F-C-C-C | Stover | $Y = 6.41 + 0.012\,N$ | 0.005 | 0.43 |
| | Ears | $Y = 4.21 + 0.026\,N$ | 0.0001 | 0.82 |
| | Whole plants | $Y = 10.62 + 0.04\,N$ | 0.0001 | 0.78 |
| F-F-C-C | Stover | $Y = 7.27 + 0.005\,N$ | 0.073 | 0.21 |
| | Ears | $Y = 5.35 + 0.05\,N - 0.002\,N^2$ | 0.042 | 0.26 |
| | Whole plants | $Y = 12.75 + 0.05\,N - 0.0002\,N^2$ | 0.010 | 0.38 |

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

higher than those in monoculture, while at Deschambault, the reverse trend was observed (L × (C vs. S) and L × (C vs. F); Tables 3 and 4). The stover N concentrations of corn following 2 consecutive years of faba bean were higher than those of corn in monoculture at St-Anselme, but not at Deschambault (L × (C vs. 2F); Tables 3 and 4).

## N Uptake of Forage Corn

At both locations, with 2 consecutive years of faba bean and corn as previous crops (F–F–C–C sequence), the stover, ear and whole-plant N uptake of the second subsequent corn crop were higher than those in monoculture (C vs. 2F; Table 1; Figs. 3 and 4). Two consecutive years of soybean and corn as previous crops (S–S–C–C sequence) had

Table 3. Summary from the analyses of variance for N concentration (%) of forage corn at St-Anselme and Deschambault in 1990

| Source of variation | df | Stover | Ears | Whole plants |
|---|---|---|---|---|
| | | (Mean squares) | | |
| Locations (L) | 1 | (0.17) | (0.05) | (0.000) |
| Replications (within) L | 6 | 0.02 | 0.003 | 0.006 |
| Previous crops (PC) | 4 | 0.008 | 0.02*** | 0.005 |
| $C^z$ vs. $S^y$ | 1 | 0.007 | 0.009 | 0.002 |
| C vs. $F^x$ | 1 | 0.005 | 0.04** | 0.006 |
| C vs. 2 $S^w$ | 1 | 0.001 | 0.01 | 0.007 |
| C vs. 2 $F^v$ | 1 | 0.006 | 0.07*** | 0.018* |
| Nitrogen (N) | 3 | 0.85*** | 0.12*** | 0.56*** |
| $N_L{}^u$ | 1 | 2.55*** | 0.29*** | 1.69*** |
| $N_Q{}^t$ | 1 | 0.0 | 0.04** | 0.001 |
| L × PC | 4 | 0.01* | 0.01* | 0.002 |
| L × (C vs. S) | 1 | 0.03** | 0.001 | 0.002 |
| L × (C vs. F) | 1 | 0.02* | 0.02* | 0.000 |
| L × (C vs. 2 S) | 1 | 0.01 | 0.00 | 0.000 |
| L × (C vs. 2 F) | 1 | 0.03** | 0.00 | 0.003 |
| Error | 114 | 0.004 | 0.004 | 0.003 |
| CV (%) | | 8.3 | 4.8 | 5.8 |
| 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.

significant effects on corn N uptake compared with the monoculture, particularly at Deschambault although differences between locations were not significant (C vs. Table 1; Figs. 3 and 4). At both locations, the ear and whole-plant N uptake were generally higher than those of corn from the monoculture when 50, 100 and 150 kg N ha$^{-1}$ were applied (Figs. 3 and 4). Continuous corn (C–C–C–C) and faba bean grown 3 yr previously (F–C–C–C) differed as previous crops, particularly at Deschambault for the ear N uptake (C vs. F; Table 1; Fig. 4). There were rotation effects at 100 and 150 kg N ha$^{-1}$ at Deschambault and at 100 kg N ha$^{-1}$ at St-Anselme for the ear N uptake of corn following soybean grown three years earlier (S–C–C–C sequence).

The N uptake of stover, ears and whole plants increased linearly with the N application for all previous crop sequences at both locations (Tables 1 and 5; Figs. 3 and 4). Cropping sequences which showed a significant quadratic response to the N application were the S–C–C–C sequence at St-Anselme, and the F–F–C–C sequence at Deschambault, both for ear and whole-plant N uptake (Table 5; Figs. 3 and 4). The two locations differed significantly in their response to N application for ear N uptake, with the linear response to the N application being more pronounced at St-Anselme than at Deschambault (L × $N_L$, Table 1; Figs. 3 and 4).

## N Fertilizer Replacement Values

At both locations, on DMY and N uptake bases, the NFRV of crop sequences involving soybean (S–C–C–C and S–S–C–C) were generally lower than 0 kg N ha$^{-1}$ for the stover, ear and whole-plant DMY and N uptake, except for the ear DMY of the S–S–C–C sequence at St-Anselme, where it

Table 4. N concentration (%) of forage corn as influenced by N rates and previous crops at St-Anselme and Deschambault in 1990

| Treatments | | St-Anselme | | | Deschambault | | |
|---|---|---|---|---|---|---|---|
| | | Stover | Ears | Whole plants | Stover | Ears | Whole plants |
| | | (%) | | | | | |
| C[z]-C-C-C | 0 N | 0.54 | 1.28 | 0.85 | 0.67 | 1.18 | 0.87 |
| | 50 N | 0.63 | 1.27 | 0.98 | 0.82 | 1.21 | 0.98 |
| | 100 N | 0.78 | 1.31 | 1.07 | 0.88 | 1.27 | 1.06 |
| | 150 N | 0.93 | 1.36 | 1.15 | 1.01 | 1.36 | 1.18 |
| S[y]-C-C-C | 0 N | 0.60 | 1.28 | 0.88 | 0.65 | 1.18 | 0.88 |
| | 50 N | 0.65 | 1.30 | 0.98 | 0.69 | 1.22 | 1.00 |
| | 100 N | 0.79 | 1.38 | 1.12 | 0.87 | 1.29 | 1.07 |
| | 150 N | 0.92 | 1.39 | 1.17 | 0.91 | 1.39 | 1.14 |
| S-S-C-C | 0 N | 0.56 | 1.29 | 0.88 | 0.60 | 1.23 | 0.92 |
| | 50 N | 0.69 | 1.30 | 0.98 | 0.81 | 1.23 | 0.98 |
| | 100 N | 0.85 | 1.36 | 1.11 | 0.87 | 1.34 | 1.09 |
| | 150 N | 0.93 | 1.36 | 1.16 | 1.02 | 1.36 | 1.19 |
| F[x]-C-C-C | 0 N | 0.57 | 1.30 | 0.88 | 0.72 | 1.40 | 0.95 |
| | 50 N | 0.70 | 1.22 | 0.95 | 0.73 | 1.26 | 0.99 |
| | 100 N | 0.86 | 1.36 | 1.12 | 0.88 | 1.35 | 1.08 |
| | 150 N | 0.96 | 1.39 | 1.17 | 0.96 | 1.36 | 1.16 |
| F-F-C-C | 0 N | 0.62 | 1.37 | 0.93 | 0.67 | 1.29 | 0.92 |
| | 50 N | 0.73 | 1.30 | 1.03 | 0.77 | 1.27 | 1.01 |
| | 100 N | 0.85 | 1.38 | 1.09 | 0.86 | 1.34 | 1.08 |
| | 150 N | 0.93 | 1.46 | 1.21 | 0.99 | 1.38 | 1.16 |
| Standard error | | 0.07 | 0.03 | 0.06 | 0.07 | 0.04 | 0.05 |

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

reached 4 kg N ha$^{-1}$ (Table 6). At Deschambault, on a DMY basis, the NFRV of faba bean grown 3 yr previously was 0 kg N ha$^{-1}$ for the stover but lower than 0 kg N ha$^{-1}$ for the ears and whole plants (Table 6); at the same location, on a N uptake basis, the NFRV for faba bean grown 3 yr previously were 6 kg N ha$^{-1}$ for both fractions and whole plants (Table 6). At St-Anselme, for the same previous crop sequence, the NFRV were 44, 8 and 19 kg ha$^{-1}$ on a DMY basis and 30, 12 and 19 kg N ha$^{-1}$ on a N uptake basis, for the stover, ears and whole plants, respectively (Table 6). The NFRV of 2 consecutive years of faba bean for a second subsequent corn crop at St-Anselme were 19, 10 and 10 kg N ha$^{-1}$ on a DMY basis, and on a N uptake basis, 33, 12 and 19 kg N ha$^{-1}$ for the stover, ears and whole plants, respectively (Table 6). At Deschambault, the NFRV of 2 consecutive years of faba bean (DMY basis) were 50, 29 and 44 kg N ha$^{-1}$ and on a N uptake basis, 20, 39 and 39 kg N ha$^{-1}$, for the stover, ears and whole plants, respectively.

In our study, corn generally reached maximum DMY and N uptake between 100 and 150 kg N ha$^{-1}$, depending on location and previous crop sequences. Corn which was preceded by previous legumes (1 or 2 yr of either faba bean or soybean) generally reached maximum DMY and N uptake at ca. 100 kg N ha$^{-1}$, at values similar to those obtained for corn in monoculture at 150 kg N ha$^{-1}$. Recommendations for N fertilizer can be established on the basis of NFRVs (DMY and N uptake bases) and N response of corn from the different crop sequences. At St-Anselme,

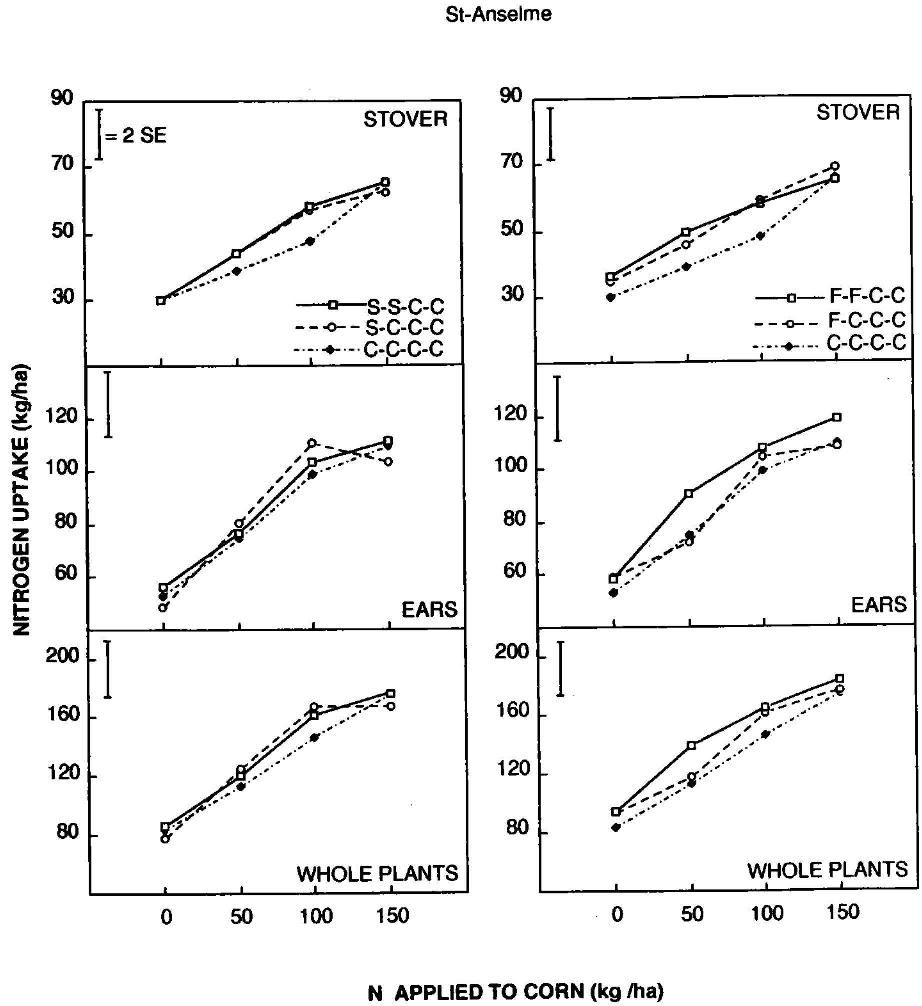


Fig. 3. N uptake of forage corn as second subsequent crop after 2 consecutive years of faba bean (F–F–C–C) and soybean (S–S–C–C), after faba bean (F–C–C–C) and soybean (S–C–C–C) grown 3 yr previously and in monoculture (C–C–C–C) at St-Anselme. Vertical bars represent 2 standard errors of mean ($n$ =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

the whole-plant DMY of corn from the monoculture reached a maximum at ca. 150 kg N ha$^{-1}$; N application could be lowered by ca. 20 kg N ha$^{-1}$ with the F–F–C–C sequence; thus, about 130 kg N ha$^{-1}$ would be sufficient for a second subsequent corn crop from this crop sequence; similar conclusions can be reached for the F–C–C–C sequence. At Deschambault, the whole-plant maxium DMY and N uptake of corn from the monoculture were achieved at ca. 150 kg N ha$^{-1}$; NFRVs suggest a reduction of ca. 40 kg N ha$^{-1}$ in N fertilizer with the F–F–C–C sequence; therefore, a N level of 110 kg N ha$^{-1}$would be sufficient to support maximum DMY and N uptake. For the F–C–C–C sequence at Deschambault, although the NFRV was nil (DMY basis) or only slightly

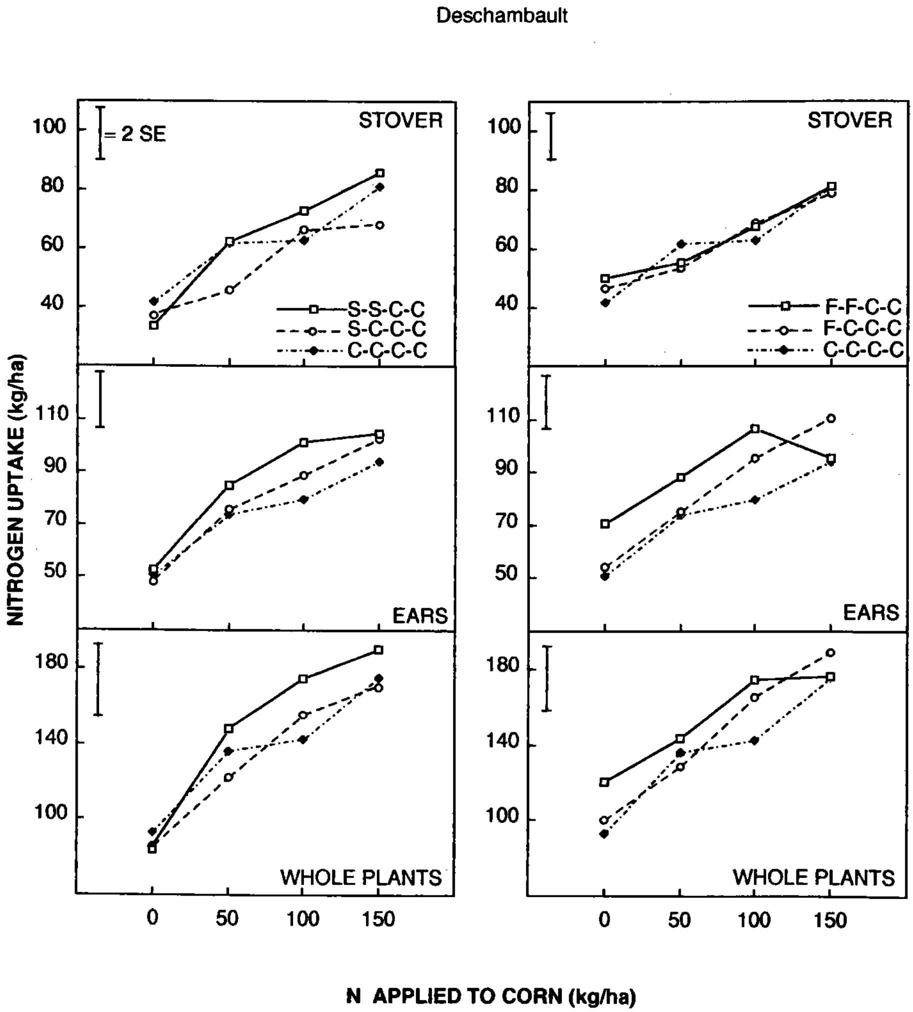


Fig. 4. N uptake of forage corn as second subsequent crop after 2 consecutive years of faba bean (F–F–C–C) and soybean (S–S–C–C), after faba bean (F–C–C–C) and soybean (S–C–C–C) grown 3 yr previously and in monoculture (C–C–C–C) at Deschambault. Vertical bars represent 2 standard errors of mean ($n$ = 48).

positive (6 kg N ha$^{-1}$) (N uptake basis), rotation effects were nevertheless present at some N levels; the data indicate that a N level of ca. 110 kg N ha$^{-1}$ would be sufficient to obtain DMY and N uptake similar to those obtained at 150 kg N ha$^{-1}$ for corn from the monoculture.

Although the NFRV obtained for the crop sequences involving 1 or 2 years of soybean were nil, there were nevertheless rotation effects when N was applied (Figs 1–4). At St-Anselme, for the S–C–C–C and S–S–C–C sequences, a N level of ca. 100 kg N ha$^{-1}$ would be sufficient to achieve the same DMY and N uptake as corn grown in monoculture and fertilized with 150 kg N ha$^{-1}$ (Figs. 1 and 3). At Deschambault, there were greater differences between these two crop sequences;

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 1990

| Crop sequences | Plant fraction | Equations | Pr > F | $R^2$ |
|---|---|---|---|---|
| | | *St-Anselme* | | |
| C[z]-C-C-C | Stover | $Y = 28.06 + 0.23\,N$ | 0.0001 | 0.80 |
| | Ears | $Y = 55.04 + 0.38\,N$ | 0.0001 | 0.88 |
| | Whole plants | $Y = 83.10 + 0.61\,N$ | 0.0001 | 0.88 |
| S[y]-C-C-C | Stover | $Y = 31.59 + 0.22\,N$ | 0.0001 | 0.77 |
| | Ears | $Y = 46.53 + 0.98\,N - 0.004\,N^2$ | 0.0001 | 0.86 |
| | Whole plants | $Y = 75.88 + 1.34\,N - 0.005\,N^2$ | 0.0001 | 0.89 |
| S-S-C-C | Stover | $Y = 31.07 + 0.24\,N$ | 0.0001 | 0.88 |
| | Ears | $Y = 58.15 + 0.38\,N$ | 0.0001 | 0.90 |
| | Whole plants | $Y = 89.23 + 0.62\,N$ | 0.0001 | 0.92 |
| F[x]-C-C-C | Stover | $Y = 34.52 + 0.23\,N$ | 0.0001 | 0.77 |
| | Ears | $Y = 58.39 + 0.35\,N$ | 0.0001 | 0.81 |
| | Whole plants | $Y = 92.82 + 0.58\,N$ | 0.0001 | 0.89 |
| F-F-C-C | Stover | $Y = 37.63 + 0.19\,N$ | 0.0001 | 0.66 |
| | Ears | $Y = 64.04 + 0.39\,N$ | 0.0001 | 0.76 |
| | Whole plants | $Y = 101.67 + 0.58\,N$ | 0.0001 | 0.82 |
| | | *Deschambault* | | |
| C-C-C-C | Stover | $Y = 44.00 + 0.24\,N$ | 0.0001 | 0.75 |
| | Ears | $Y = 54.60 + 0.27\,N$ | 0.0001 | 0.76 |
| | Whole plants | $Y = 98.60 + 0.51\,N$ | 0.0001 | 0.84 |
| S-C-C-C | Stover | $Y = 37.18 + 0.23\,N$ | 0.0001 | 0.72 |
| | Ears | $Y = 53.08 + 0.34\,N$ | 0.0001 | 0.80 |
| | Whole plants | $Y = 90.27 + 0.57\,N$ | 0.0001 | 0.85 |
| S-S-C-C | Stover | $Y = 38.66 + 0.33\,N$ | 0.0001 | 0.72 |
| | Ears | $Y = 60.06 + 0.34\,N$ | 0.0001 | 0.75 |
| | Whole plants | $Y = 98.72 + 0.68\,N$ | 0.0001 | 0.81 |
| F-C-C-C | Stover | $Y = 44.96 + 0.23\,N$ | 0.0005 | 0.59 |
| | Ears | $Y = 55.36 + 0.38\,N$ | 0.0001 | 0.85 |
| | Whole plants | $Y = 100.33 + 0.60\,N$ | 0.0001 | 0.88 |
| F-F-C-C | Stover | $Y = 47.77 + 0.21\,N$ | 0.0001 | 0.77 |
| | Ears | $Y = 68.79 + 0.62\,N - 0.003\,N^2$ | 0.0108 | 0.38 |
| | Whole plants | $Y = 118.47 + 0.72\,N - 0.002\,N^2$ | 0.0001 | 0.67 |

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

with the S–C–C–C sequence, no substantial reduction in N fertilization would have been possible, and a N level of 150 kg N ha$^{-1}$ would have been necessary. In contrast, with the S–S–C–C sequence, 100 kg N ha$^{-1}$ would have been adequate for the second succeeding corn crop (Figs. 2 and 4).

## CONCLUSION

Our results indicate that faba bean grown for 1 yr had limited but significant benefical effects on the DMY and N uptake of a third subsequent corn crop, presumably due more to rotation effects other than N-rotation effects. Faba bean grown for 2 consecutive years had a greater impact on the DMY and N uptake of a second subsequent corn crop, with significant N-rotation effects, as well as other rotation effects. Consequently, faba bean grown for grain could be an alternative to the intensive and expensive application of N fertilizer. Although soybean was a poor

Table 6. Estimated N-fertilizer replacement values (NFRV) of legumes in forage-corn production at St-Anselme and Deschambault in 1990

| Crop sequences | N fertilizer replacement values (N, kg 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-C[x] | <0 | <0 | <0 | <0 | <0 | <0 | <0 | <0 | <0 | <0 | <0 | <0 |
| S-S-C-C | <0 | 4 | <0 | <0 | <0 | <0 | <0 | <0 | <0 | <0 | <0 | <0 |
| F[w]-C-C-C | 44 | 8 | 19 | 0 | <0 | <0 | 30 | 12 | 19 | 6 | 6 | 6 |
| F-F-C-C | 19 | 10 | 10 | 50 | 29 | 44 | 33 | 12 | 19 | 20 | 39 | 39 |

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

N source in the crop sequences investigated here, it nevertheless exhibited rotation effects, mostly at Deschambault, suggesting that this crop can contribute to increased corn yields compared with the monoculture, and can contribute in reducing N requirements of corn as well. Rotation effects ofter than those related to N provision and/or conservation of soil N apparently contributed to the increased yields observed; the mechanisms implied need further investigation.

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