Forage corn dry-matter yields and N uptake as affected by previous legumes and N fertilizer

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Paré, T., Chalifour, F.-P., Bourassa, J. and Antoun, H. 1992. **Forage corn dry-matter yields and N uptake as affected by previous legumes and N fertilizer.** Can. J. Plant Sci. **72**: 699–712. Field experiments were conducted in 1987 and 1988 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. In monoculture, or following a legume, corn (*Zea mays* L.) Pioneer 3979 was fertilized with 0, 50, 100 or 150 kg N ha^{-1}, and faba bean (*Vicia faba* L.) Outlook and soybean (*Glycine max* [L.] Merr.) Maple Amber received 20 kg N ha^{-1} as NH_4NO_3. In 1987, the whole-plant dry-matter yields (DMY) of corn increased linearly with the supply of N at St-Anselme and Deschambault. The stover and whole-plant N uptake, also increased linearly with the N levels at both locations, but the supply of N had no effect on the ear N uptake. In 1988, at St-Anselme and at Deschambault, the ear, stover and whole-plant DMY of plants not receiving N and following faba bean were significantly higher than those in monoculture or following soybean and not fertilized with N; these differences between previous crops were more evident at St-Anselme than at Deschambault. At both locations, the DMY of the stover, ears and whole plants of corn were more responsive to the increased N levels following soybean or corn. At both locations, the N uptake of corn following faba bean did not increase with the N levels in contrast to corn following corn or soybean. The N-fertilizer replacement values (NFRV) for soybean (on the basis of corn DMY) were negligible or lower than 0 kg N ha^{-1} at both locations. At St-Anselme, the values for faba bean were higher than 150 kg N ha^{-1}, but averaged 32 kg N ha^{-1} at Deschambault (DMY basis). On the basis of corn N uptake, the NFRV of faba bean ranged from 92 kg N ha^{-1} for ears and was higher than 150 kg N ha^{-1} for whole plants at St-Anselme, and varied from 37 kg N ha^{-1} for stover to 44 kg N ha^{-1} for ears at Deschambault.

Key words: Previous crop, forage corn, soybean, faba bean, N-fertilizer replacement value

Paré, T., Chalifour, F.-P., Bourassa, J. et Antoun, H. 1992. **Effets des précédents légumineuses et de la fertilisation azotée sur les rendements en matière sèche et sur l'absorption d'N du maïs fourrage.** Can. J. Plant Sci. **72**: 699–712. Des expériences de champ ont été réalisées en 1987 et 1988 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. En monoculture ou subséquemment à une légumineuse, le maïs (*Zea mays* L.) Pioneer 3979 a reçu 0, 50, 100 ou 150 kg N ha^{-1} et la féverole (*Vicia faba* L.) Outlook, de même que le soja (*Glycine max* [L.] Merr.) Maple Amber ont reçu 20 kg N ha^{-1}, sous forme de NH_4NO_3. En 1987, les rendements en matière sèche (RMS) des plantes entières de maïs ont augmenté de façon linéaire avec les doses d'N à St-Anselme et à Deschambault. L'absorption d'N des cannes et des plantes entières a également augmenté proportionnellement aux doses d'N aux deux sites, mais l'apport d'N n'a pas eu d'effet sur l'absorption d'N des épis. En 1988, à St-Anselme et à Deschambault, les RMS des épis, des cannes et des plantes entières de maïs n'ayant pas reçu d'N et subséquentes à la féverole, étaient significativement supérieurs à ceux suivant le maïs et le soja et n'ayant pas reçu d'N; les différences étaient plus marquées à St-Anselme qu'à Deschambault. Aux deux sites, les RMS des cannes, des épis et des plantes entières du maïs ont augmenté avec les niveaux d'N après le soja et le maïs. Aux deux sites, l'absorption

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d'N du maïs après la féverole n'a pas augmenté avec la dose d'N contrairement au maïs en monoculture ou suivant le soja. Les valeurs de remplacement en fertilisant azoté (VRFA) (sur la base du RMS du maïs) pour le soja étaient négligeables ou inférieures à 0 kg N ha^{-1} aux deux sites. A St-Anselme, les VRFA pour la féverole étaient supérieures à 150 kg N ha^{-1}, mais ont été en moyenne de 32 kg N ha^{-1} à Deschambault (base du RMS). Sur la base de l'absorption d'N, les VFRA ont varié de 92 kg N ha^{-1} pour les épis à plus de 150 kg N ha^{-1} pour les plantes entières à St-Anselme et de 37 kg N ha^{-1} pour les cannes à 44 kg N ha^{-1} pour les épis à Deschambault.

Mots clés: Précédent cultural, maïs fourrage, soja, féverole, valeur de remplacement en fertilisant azoté

In agriculture, legumes play a major role since, in addition to being a good source of protein, they provide an alternate and inexpensive source of N for themselves as well as for succeeding non-legume crops (Muyinda et al. 1988). Consequently, including legumes in crop rotations with corn could be an economic alternative to corn monoculture, common throughout the Province of Québec. Indeed, it has often been observed that previous legumes can enhance the yields of subsequent cereal crops grown on the same soil (De et al. 1983; Hanson et al. 1988). Legumes can fulfill part of their N requirements by forming N_2-fixing symbioses with bacteria from the *Bradyrhizobium* and *Rhizobium* genera. Under conditions favoring N_2 fixation, legumes can also leave residual nitrogen in the soil that becomes available to the succeeding crop (Senaratne and Hardarson 1988). Some studies indicate that legumes produce high yields of good-quality grain or forage (Hesterman et al. 1986; Badaruddin and Meyer 1989). However, harvesting the crop for grain or forage means that only a small proportion of the fixed N_2 is returned to the soil; nevertheless, usually the earnings from harvest are considerably higher than the cost of replacing the N with commercial fertilizers, because other benefits, called rotation effects, which are not directly related to legume N, can contribute to subsequent crop yield increases (Baldock et al. 1981; Wright and Coxworth 1987). According to Baldock et al. (1981), in terms of yield, the total rotation effect is the yield differential with zero N application, the rotation effect is the yield differential at the highest N rate, and the N-rotation effect is the total minus the rotation effect.

Many methods have been used to measure the amount of N contributed by legumes to non-legumes in a cropping system (Hesterman 1988). The N-fertilizer replacement value, defined as the quantity of fertilizer N required to achieve the same yield in a continuous non-legume crop, can provide an estimate of the reduction in fertilizer N needs of subsequent non-legume crops (Fox and Piekielek 1988).

Several rotation studies including soybean (*Glycine max* [L.] Merr.) and corn have been conducted (Claassen and Kissel 1984; Hesterman et al. 1986; Power et al. 1986; Crookston et al. 1991). Hesterman et al. (1986) reported that second-phase (i.e., second-year) corn grain yields were greater after soybean than in corn monoculture. Claassen and Kissel (1984) noted an increase in DMY of nearly 2.5 times for corn grown after soybeans and not receiving nitrogen than for continuous corn. Few data have been reported for faba bean (*Vicia faba* L.) as previous crop to non-legume species. Recently, Wright (1990) reported subsequent barley (*Hordeum vulgare* L.) yield increases following faba bean in Northeastern Saskatchewan. N balance studies for faba bean in Eastern Canada by Patriquin et al. (1980) showed that if the straw was removed from the field, as it is when plants are used for silage, there is a very large negative N balance despite the high N_2 fixation. Senaratne and Hardarson (1988) quantified the residual N effect of faba bean by using an isotopic method and observed positive effects on the soil N budget and on subsequent cereal production.

In Quebec, about 61 000 ha are devoted to forage-corn (*Zea mays* L.) monoculture

(Tabi et al. 1990), and there are no available data regarding the production of forage corn following annual legumes. The objective of this study was to determine the effects of two annual legumes (faba bean and soybean) as previous crops on subsequent forage-corn DMY and N uptake compared to continuous corn, and to evaluate interactions of previous legumes and N rates under the climatic conditions of Eastern Quebec; this bioclimatic zone is characterized by 1530 growing degree-days, 126 frost-free days and 519 mm of rainfall, from May to September (Dubé et al. 1989).

MATERIALS AND METHODS

Field experiments were conducted during the 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 (Typic Orthic Humic Gleysol) at Deschambault in Eastern Quebec. As cropping history, at St-Anselme the field was grown with barley (*Hordeum vulgare* L.) in 1982, wheat (*Triticum aestivum* L.) in 1983, followed by barley in 1984, alfalfa (*Medicago sativa* L.) in 1985 and barley in 1986. At Deschambault, from 1982 to 1986, the field was grown with barley. Some properties of the soils are shown in Table 1; the soil pH was measured in water (1:2) and available P was assessed using the Bray P_2 method after extraction with 0.03 N NH_4F + 0.1 N HCl (McKeague 1978). Exchangeable K, Ca and Mg were determined by atomic absorption spectrophotometry after extraction with 1 N NH_4OAc (McKeague 1978). Soil organic matter was estimated by the Walkley and Black modified method (McKeague 1978). Soil from both locations was analyzed before sowing in 1987 to determine P and K requirements. In order to apply optimum levels of nutrients (i.e., P and K) for corn growth, plots grown with corn in monoculture in 1987 and receiving the highest N level (i.e., a total of 150 kg N ha^{-1}) were used for 1988 soil tests. These elements were applied both years to maintain soil test levels at those recommended for forage-corn

production by the *Conseil des Productions Végétales du Québec* (CPVQ). In 1987, 44.2 and 40.5 kg ha^{-1} of P, 112.1 and 76.9 kg ha^{-1} of K and in 1988, 44.3 and 28.5 kg ha^{-1} of P, and 112.2 and 72.2 kg ha^{-1} of K, as 0-15-20 (both years) were topdressed and disced at St-Anselme and Deschambault, respectively. In 1987, at St-Anselme, total precipitation was 563 mm which was 126 mm below normal while at Deschambault total precipitation was 745 mm, which was 40 mm above normal; at both locations CHUs (2963 and 3150 at St-Anselme and Deschambault, respectively) were higher than normal; in 1988, rainfall was 151 and 44 mm below normal for St-Anselme and Deschambault, respectively, and CHUs (2899 and 3005 at St-Anselme and Deschambault, respectively) were higher than normal at both locations.

In 1987, crops were established on 5.25 × 5-m plots in a randomized complete block design with four replications at both locations. Pioneer 3979 corn, Outlook faba bean, and Maple Amber soybean were used in these field experiments; in each replication, there were four plots of corn monoculture receiving different levels of N, and four plots of each legume. The crops were sown on 13 and 18 May 1987 at St-Anselme and Deschambault, respectively. For corn, between and within-row spacings were 72 and 15 cm, respectively, with a final canopy density of 92 592 plants ha^{-1}. For faba bean and soybean, 505 051 seeds ha^{-1} were planted, with between and within-row spacings of 18 and 11 cm, respectively.

Atrazine (1.5 kg a.i. ha^{-1}), and metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methyl) acetamide] (1.8 kg a.i. ha^{-1}) for corn, metobromuron [2-chloro-4 (ethylamino)-6-(isopropylamino)-S-triazine] (1.5 kg a.i. ha^{-1}) and metolachlor (1.8 kg a.i. ha^{-1}) for soybean and metribuzine [3-(4-bromo-phenyl-1-methoxy-1-methylureal] (0.6 kg a.i. ha^{-1}) and metolachlor (1.8 kg ha^{-1}) for faba bean were used as postemergence herbicides. Following emergence and during the growing season, weeds were hand-controlled when necessary. Corn was fertilized (banding rows 15 cm apart) twice with a total of 0, 50, 100 or 150 kg N ha^{-1} as NH_4NO_3; one fraction (0 or 25 kg N ha^{-1}) was

Table 1. Some properties of the soils (0–15 cm) at St-Anselme and Deschambault before sowing in 1987

Locations	Texture	pH	Organic matter	P (Bray 2)	K	Mg	Ca
						exchangeable	
			(%)		(kg ha^{-1})		
St-Anselme	loam	6.6	3.95	187	170	125	4.02
Deschambault	silty loam	6.5	4.30	218	228	394	5.55

applied at planting and the other fraction (0, 25, 75 or 125 kg N ha^{-1}) at the six- to eight-leaf stage (tassel initiation). This method of application corresponds to optimal timing of application for forage corn production in Eastern Québec (Chalifour 1982). The legume seeds were inoculated at planting into the drill row with granular inoculum (Liphatech Inc., Milwaukee, WI) containing strains of *Bradyrhizobium japonicum* (soybean) and *Rhizobium leguminosarum* biovar *viciae* (faba bean). The legumes received 20 kg N ha^{-1} as NH_4NO_3 at planting. Each corn plot consisted of seven rows and the three central rows were harvested on 7 and 9 October at St-Anselme and at Deschambault, respectively, with a forage harvester after the ears were removed 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 content was determined on ground samples after Kjeldahl digests using a Technicon autoanalyzer (Morgan et al. 1966). The N uptake was determined by multiplying the DMY of the ears, stover and whole plants by the N percentage of the respective components. The legume grains were harvested with a Wintersteïger plot combine (Wintersteïger, Salt Lake City, UT), and the residues were incorporated with a moldboard plow. In a parallel study at the same locations, Chalifour et al. (1990) studied the N_2-fixing potential of soybean an faba bean using ^{15}N methodology.

In 1988, forage-corn production was estimated on plots that received residues of the previous legume crops and on corn monoculture plots. Between- and within-row spacings and final canopy density of corn were as in 1987. The experiment was a factorial consisting of two locations, three preceding crops, and four N levels; the experimental design was a randomized complete block with four replications at each location. Crop sequences were corn monoculture (C-C), and soybean-corn (S-C) and faba bean-corn (F-C) sequences; within each replication there were four plots of corn monoculture and of legume-corn sequences; each plot received one of the four N levels (i.e., 0, 50, 100 or 150 kg N ha^{-1}) applied as in the first year of the study. Corn was sown on 12 and 21 May at St-Anselme and Deschambault, respectively. 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. Corn was harvested from the three central rows on 5 and 12 October at Deschambault and St-Anselme, respectively, and

the DMY and N uptake were estimated. The N-fertilizer replacement value (NFRV) of soybean and faba bean was estimated following the method described by Hesterman (1988), using N response curves of corn grown in monoculture.

Statistical analyses were carried out using the Statistical Analysis System Institute, Inc. (SAS 1985). 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.

RESULTS

Dry-matter Yields and N Uptake of Forage Corn in 1987

In 1987, at both locations, total precipitation and CHUs were quite favourable for growth of Pioneer 3979, the CHU requirements of this hybrid being 2325. The application of N did not increase the ear DMY at St-Anselme and Deschambault, but increased the DMY of the whole plants at both locations (Fig. 1). The DMY response of whole plants to N fertilizer can be described by the equations $Y = 15.08 + 0.0017$ N ($P > F = 0.04$ and $R^2 = 0.26$) and $Y = 16.30 + 0.0226$ N ($P > F = 0.01$ and $R^2 = 0.38$) at St-Anselme and Deschambault, respectively. Furthermore, the stover DMY increased with N application at St-Anselme ($Y = 6.06 + 0.0116$ N, $P > F = 0.03$, $R^2 = 0.38$) but not at Deschambault (Fig. 1). At both locations, the ears contributed more to the whole-plant DMY than stover (Fig. 1). 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.

The stover and whole-plant N concentrations, averaged from both locations, increased linearly with N application, but N application had no effect on the concentration of ear N (Table 2). The stover and whole-plant N uptake increased linearly with the N application at both locations, but the supply of N did not influence the ear N uptake (Fig. 1). For stover N uptake, regression equations were $Y = 40.30 + 0.21$ N ($P > F = 0.005$, $R^2 = 0.55$) at St-Anselme, and $Y = 41.81 +$
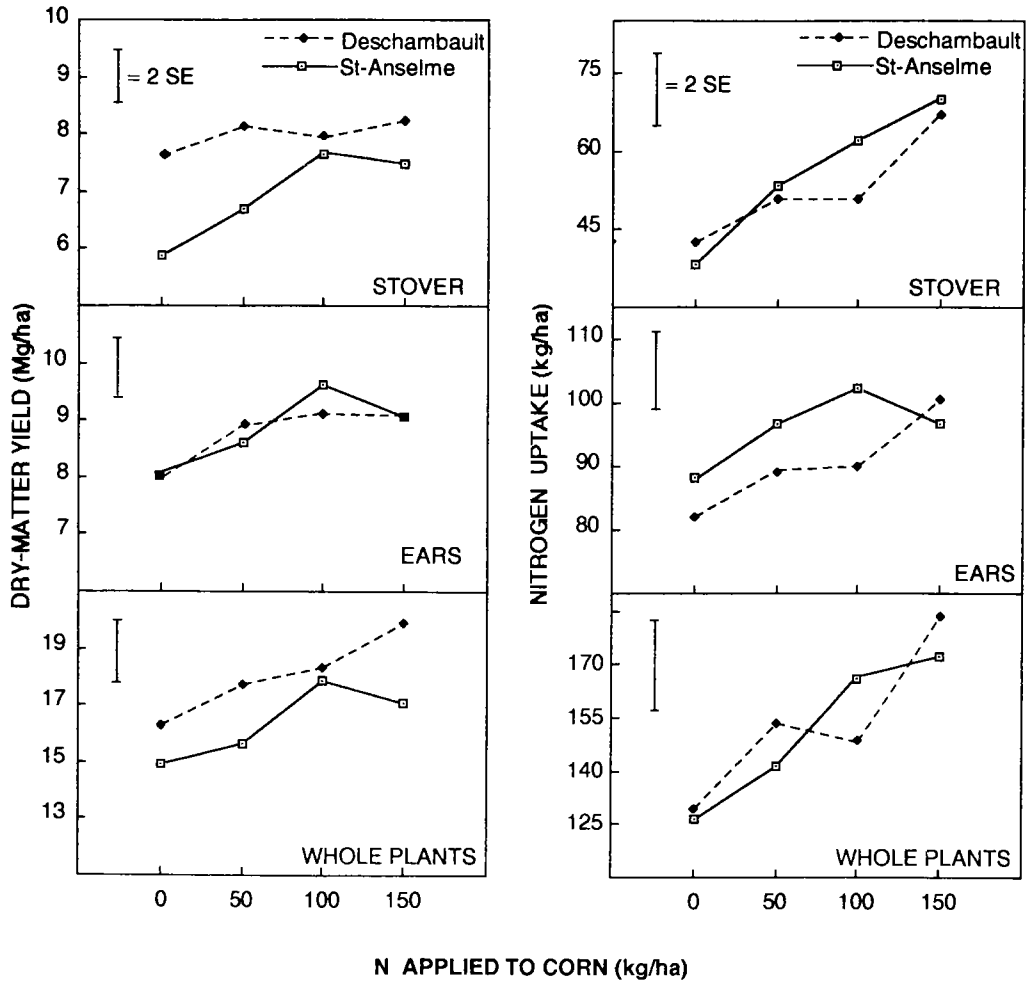
Fig. 1. First-year forage-corn dry-matter yields and N uptake.

0.15 N $(P > F = 0.001, R^2 = 0.55)$ at Deschambault; the N uptake response of whole plants to N fertilizer can be described by the equations $Y = 127.32 + 0.32$ N $(P > F = 0.004, R^2 = 0.44)$ and $Y = 130 + 0.31$ N $(P > F = 0.0006, R^2 = 0.58)$ at St-Anselme and Deschambault, respectively. The ear contribution to the whole-plant N uptake was higher than that of stover, which can be explained by the fact that the nitrogen concentrations of the ear was nearly 1.5 times greater than that of the stover (Table 2), although the ear contribution to the whole-plant DMY averaged 50% (data not shown)

at both locations and at any N level. The significant linear response of whole-plant DMY and N uptake to N application indicated that Pioneer 3979 showed its yielding potential at the highest N rates (i.e., 100 and 150 kg N ha^{-1}).

Dry-matter Yields of Forage Corn in 1988
In 1988, climatic conditions were also favorable for corn growth. The previous crops had significant effects on the corn stover, ear and whole-plant DMY (Table 3, Fig. 2). Averaged across all N levels and locations, corn DMY was significantly higher with faba

Table 2. Mean N concentrations of forage corn as influenced by fertilizer N levels at St-Anselme and Deschambault in 1987[z] and 1988[y]

	1987						1988					
	N levels				Regression		N levels				Regression	
Plant fraction	0	50	100	150	N_L[x]	N_Q[w]	0	50	100	150	N_L	N_Q
	(N concentration (%))											
Stover	0.59	0.69	0.86	0.73	***	NS	0.61	0.67	0.75	0.76	***	NS
Ears	1.05	1.05	1.02	1.08	NS	NS	1.35	1.37	1.43	1.45	**	NS
Whole plants	0.83	0.87	0.87	0.94	***	NS	1.02	1.07	1.13	1.14	***	NS

[z] Results are the means of 8 observations averaged from both locations.
[y] Results are the means of 24 observations averaged from both locations and previous crops.
[x] Linear effect of N.
[w] Quadratic effect of N.
,* Significant responses to N levels at the 0.01 and 0.001 probability levels, respectively. NS, nonsignificant.

Table 3. Summary from the analyses of variance for forage-corn dry-matter yields and N uptake at St-Anselme and Deschambault in 1988

		Dry-matter yields			N uptake		
Source of variation	df	Stover	Ears	Whole plants	Stover	Ears	Whole plants
		Mean squares					
Locations (L)	1	(0.10)	(1.17)	(0.32)	(332.60)	(6.12)	(5501)
Rep[z] (within) L	6	0.62	0.89	1.85	68.32	721.33	851.54
PC[y]	2	6.38***	3.39*	19.16**	798.77***	1106.91	4465**
C[x] vs. S[w]	1	0.03	0.04	0.09	1.26	16.53	141.83
C vs. F[v]	1	9.75***	5.53*	30.29**	1158***	1473*	5600*
Nitrogen (N)	3	5.66***	12.76***	34.08***	1712***	4122***	10310***
N_L[u]	1	13.74***	28.67***	78.03***	4503***	10450***	25448***
N_Q[t]	1	3.24*	9.61**	24.17**	502.65*	1764*	4178*
L×PC	2	2.05	1.98	8.83	422.38*	484.64	2227
L×(C vs. S)	1	0.41	0.34	2.06	155.09	23.92	165.04
L×(C vs. F)	1	3.93*	3.77	17.12*	839.26**	840.81	3969*
L×N	3	0.36	1.61	7.30	13.51	548.87	855.76
N×PC	6	1.47	1.58	5.23	238.57*	526.71	1389
N_L×(C vs. S)	1	0.01	0.02	0.00	143.55	6.51	164.46
N_L×(C vs. F)	1	1.01	3.73	6.98	466.19*	1323	4768
N_Q×(C vs. S)	1	4.96*	2.54	14.31*	154.03	691.63	984.90
N_Q×(C vs. F)	1	0.46	0.18	0.05	13.52	58.15	430.29
L×PC×N	6	0.49	0.29	0.29	43.63	218.74	410.30
L×(C vs. S) × N_L	1	0.26	0.03	0.14	15.43	211.70	174.04
L×(C vs. F) × N_L	1	0.83	0.40	0.10	41.92	1.70	58.00
L×(C vs. S) × N_Q	1	0.82	0.18	1.26	31.76	601.71	403.01
L×(C vs. F) × N_Q	1	0.01	0.05	0.30	0.09	265.56	9.61
Error	66	0.73	0.98	3.05	97.69	368.56	817.77
CV (%)		11.42	10.44	10.29	18.55	14.30	15.14

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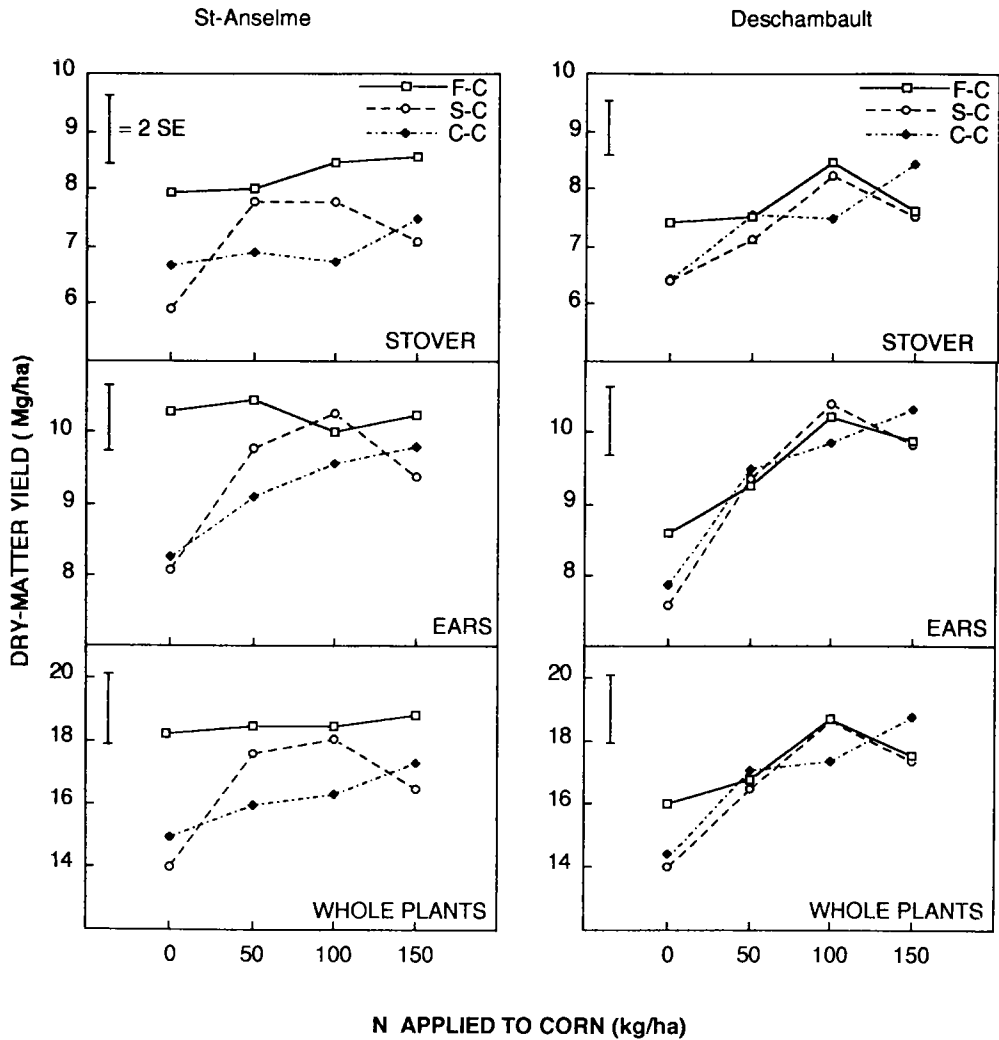*,**,*** Significant at the 0.05, 0.01 and 0.001 probability levels respectively.

Fig. 2. Dry-matter yields of second-year forage corn following faba bean (F-C), soybean (S-C) and in monoculture (C-C).

bean compared with corn as previous crop, whereas the DMY were generally similar with soybean and corn as previous crops (C vs. F and C vs. S, respectively, Table 3; Fig. 2). Averaged across all N levels, there were greater differences between faba bean and corn as previous crops at St-Anselme for corn stover and whole-plant DMY than at Deschambault (L×(C vs. F), Table 3; Fig. 2).

Generally, the DMY of the ears, stover and whole plants increased with N application, and the degree of response varied among previous crops (N_L and N_Q, Tables 3 and 4; Fig. 2). At both locations, in monoculture or following soybean, the ear and whole-plant DMY of corn increased significantly with N application (Table 4; Fig. 2). Although corn and soybean were similar as first-phase crops, averaged from all N levels and locations, there was a significant quadratic response to N for corn following soybean, which was not observed for corn in monoculture (N_Q ×

Table 4. Regression equations for forage corn dry-matter yields (Y) as a function of N rates (N) for forage corn, soybean and faba bean treatments at St-Anselme and Deschambault in 1988

Previous crops	Plant fraction	Equations	$P > F$	R^2
		St-Anselme		
Corn	Stover	$Y = 6.58 + 0.005N$	0.11	0.17
	Ears	$Y = 8.41 + 0.01 N$	0.009	0.39
	Whole plants	$Y = 15.04 + 0.014N$	0.03	0.30
Soybean	Stover	$Y = 5.98 + 0.04 N - 0.002 N^2$	0.03	0.42
	Ears	$Y = 8.06 + 0.05 N - 0.0002N^2$	0.02	0.43
	Whole plants	$Y = 14.05 + 0.09 N - 0.0005N^2$	0.01	0.48
Faba bean	Stover	$Y = 7.88 + 0.05 N$	0.30	0.07
	Ears	$Y = 10.34 - 0.001N$	0.79	0.005
	Whole plants	$Y = 18.23 + 0.003N$	0.67	0.01
		Deschambault		
Corn	Stover	$Y = 6.60 + 0.012N$	0.006	0.42
	Ears	$Y = 8.21 + 0.015N$	0.007	0.41
	Whole plants	$Y = 14.95 + 0.025N$	0.008	0.40
Soybean	Stover	$Y = 6.65 + 0.009N$	0.02	0.31
	Ears	$Y = 8.11 + 0.015N$	0.007	0.41
	Whole plants	$Y = 14.77 + 0.024N$	0.009	0.39
Faba bean	Stover	$Y = 7.52 + 0.003N$	0.02	0.32
	Ears	$Y = 8.75 + 0.010N$	0.39	0.05
	Whole plants	$Y = 16.29 + 0.012N$	0.06	0.21

(C vs. S), Tables 3 and 4; Fig. 2); this was only observed at St-Anselme, although differences between locations were not significant (L × (C vs. S) × N_Q, Tables 3 and 4; Fig. 2). At both locations, and especially at St-Anselme, without N application, the stover, ear, and whole-plant DMY of corn following soybean were lower than those in monoculture (Fig. 2). However, at St-Anselme, the stover, ear, and whole-plant DMY of corn following soybean were higher than those of the monoculture when 50 and 100 kg N ha^{-1} were applied (Fig. 2); this was not observed at 150 kg N ha^{-1}, due to a decrease in DMY of both plant fractions and of the whole plant (Fig. 2). Similar results were obtained for the Deschambault location, except that DMY were similar at 50 kg N ha^{-1}, and differences between corn and soybean as previous crops were less than at St-Anselme (Fig. 2). At St-Anselme, with faba bean as previous crop, the DMY of stover, ears and whole plants did not increase significantly with N application (Table 4; Fig. 2). At Deschambault, however, only the DMY of ears did not increase significantly in

response to N application, although there was a net tendency for increased DMY in response to increasing N levels (Table 4; Fig. 2). At both locations, without N application, the stover, ear and whole-plant DMY of corn following faba bean outyielded those of corn in monoculture (Fig. 2).

At both sites, with soybean as previous crop, despite the apparent absence of a N contribution, there were rotational effects observed for both plant fractions and the whole plant (Fig. 2); they were most apparent at St-Anselme, at the intermediate N levels (i.e., 50 and 100 kg N ha^{-1}). At Deschambault, they were observable only at 100 kg N ha^{-1}. Rotational effects apparently not linked to N contribution were observed for faba bean at 150 kg N ha^{-1} at St-Anselme, for both plant fractions and the whole plant, but only up to 100 kg N ha^{-1} at Deschambault, due to a decrease in DMY at the highest N level (Fig. 2).

N Concentrations and Uptake of Forage Corn in 1988

In 1988, there were no significant differences in N concentration in different plant fractions

due to locations or preceding crops (data not shown); therefore, the data have been averaged from locations and preceding crops (Table 2). The stover, ear and whole-plant N concentrations increased linearly with the N levels applied (Table 2).

At St-Anselme and Deschambault, the N uptake of stover, ears and whole-plant corn following soybean or grown in monoculture increased significantly with N application (Tables 3 and 5; Fig. 3). In contrast, there were no significant N uptake increases at either location in response to N application when corn was preceded by faba bean (Tables 3 and 5; Fig. 3).

There were slight differences in N response between the DMY and N uptake; at St-Anselme, the stover N uptake of corn grown in monoculture increased significantly in contrast to stover DMY (Tables 4 and 5; Figs. 2 and 3). The only other difference noted was that at Deschambault, the stover N uptake of corn following faba bean did not increase significantly in response to N application, unlike the stover DMY (Tables 4 and 5; Figs. 2 and 3). The additional significant effect of N application

on stover N uptake is presumably due to significant increases in N concentration in response to N application.

N-fertilizer Replacement Values of Legumes

At St-Anselme, the stover, ear and whole-plant DMY of 0 N corn following faba bean were greater than the continuous corn yield at any N level, whereas the DMY of 0 N corn following soybean was lower than DMY of 0 N corn in monoculture, making it impossible to estimate the NFRV (DMY basis) by the method described by Hesterman (1988). Thus, we arbitrarily chose to estimate the NFRV higher than 150 kg N ha^{-1} for faba bean and lower than 0 kg N ha^{-1} for soybean (Table 6). At Deschambault, the NFRV of soybean were the same as those estimated at St-Anselme (Table 6). At the same location the NFRV of faba bean varied between 22 (ears) and 42 (stover) kg N ha^{-1} (Table 6).

At St-Anselme, the NFRV of faba bean based on N uptake varied between 92 (ears) and higher than 150 (whole plants) kg N ha^{-1} (Table 6). At Deschambault, these values varied between 37 (stover) and 44

Table 5. Regression equations for forage-corn N uptake (Y) as a function of N rates (N) for forage corn, soybean and faba bean treatments at St-Anselme and Deschambault in 1988

| Previous crops	Plant fraction	Equations	$P > F$	R^2
		St-Anselme		
Corn	Stover	$Y = 37.50 + 0.15\ N$	0.0001	0.70
	Ears	$Y = 117.67 + 0.20\ N$	0.010	0.40
	Whole plants	$Y = 155.42 + 0.39\ N$	0.010	0.40
Soybean	Stover	$Y = 37.50 + 0.45\ N - 0.002\ N^2$	0.015	0.47
	Ears	$Y = 109.74 + 0.99\ N - 0.0058N^2$	0.057	0.37
	Whole plants	$Y = 145.25 + 1.48\ N - 0.0082N^2$	0.015	0.50
Faba bean	Stover	$Y = 58.32 + 0.084N$	0.13	0.15
	Ears	$Y = 142.50 + 0.29\ N - 0.0015N^2$	0.51	0.097
	Whole plants	$Y = 216.89 - 0.033N$	0.82	0.004
		Deschambault		
Corn	Stover	$Y = 37.67 + 0.19\ N$	0.0001	0.71
	Ears	$Y = 107.46 + 0.29\ N$	0.003	0.46
	Whole plants	$Y = 147.07 + 0.46\ N$	0.0004	0.60
Soybean	Stover	$Y = 39.62 + 0.12\ N$	0.026	0.30
	Ears	$Y = 100.99 + 0.34\ N$	0.003	0.48
	Whole plants	$Y = 140.61 + 0.46\ N$	0.003	0.48
Faba bean	Stover	$Y = 48.36 + 0.067N$	0.23	0.10
	Ears	$Y = 122.73 + 0.118N$	0.22	0.10
	Whole plants	$Y = 171.09 + 0.185N$	0.15	0.14
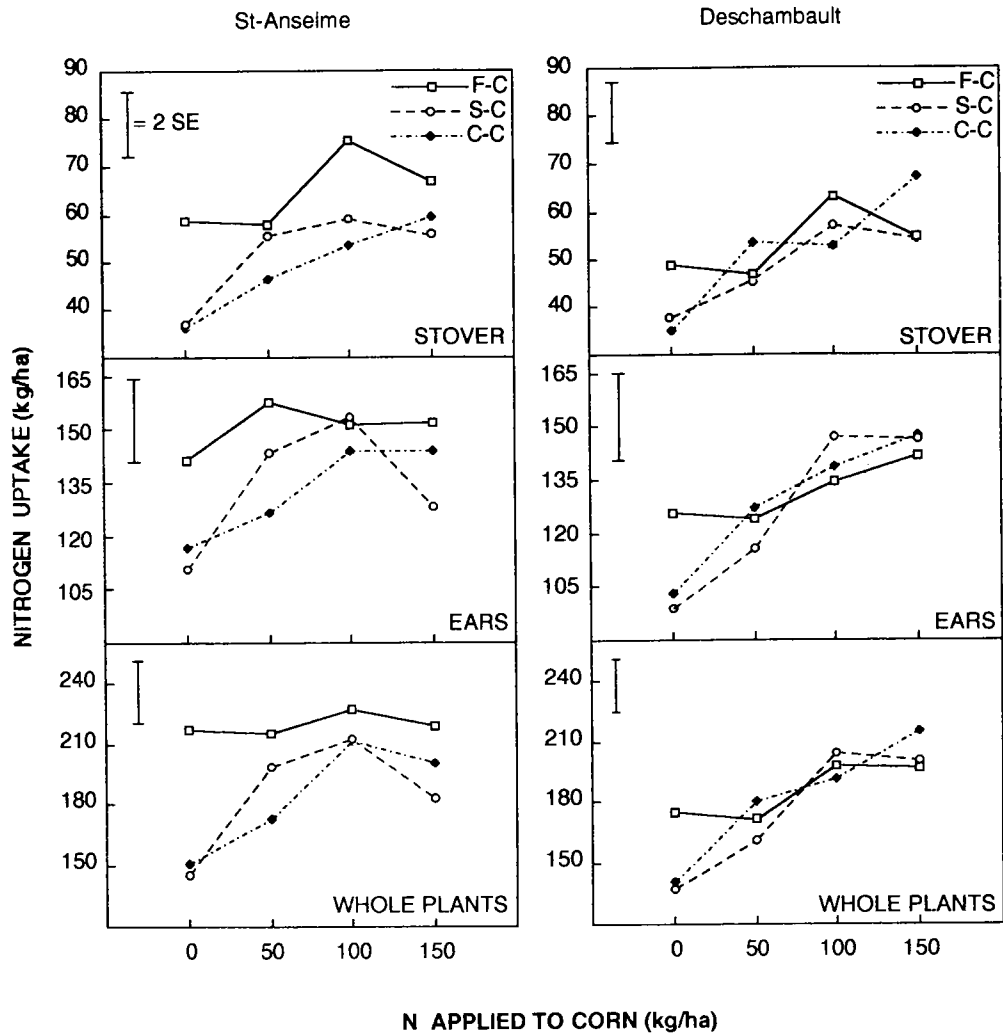
Fig. 3. N uptake of second year forage corn following faba bean (F-C), soybean (S-C) and in monoculture (C-C).

(ears) kg N ha^{-1}. At both locations, the NFRV of soybean were lower than 0 kg N ha^{-1} for forage-corn ear and whole-plant N uptake, but were 4 and 8 kg N ha^{-1} for stover N uptake at St-Anselme and Deschambault, respectively (Table 6).

DISCUSSION

In 1987, without N application, the DMY and N uptake of ears obtained at St-Anselme and Deschambault were similar to those obtained

with all N levels; this suggests that substantial amounts of available N were supplied to corn through mineralization of soil organic matter during the growing season, as has been described by Bundy and Carter (1988). In addition, remobilization of reduced N from stover may have been sufficient to maintain similar N uptake of ears at all N levels (Below et al. 1981). In contrast, there were significant increases in stover and whole-plant N uptake at both locations, in response to N

Table 6. N-fertilizer replacement values (NFRV) of soybean and faba bean for forage corn as estimated by N fertilizer response functions

	N-fertilizer replacement values (kg N ha^{-1})											
	Dry-matter yield basis						N uptake basis					
	St-Anselme			Deschambault			St-Anselme			Deschambault		
Previous legume	Stover	Ears	WP^z	Stover	Ears	WP	Stover	Ears	WP	Stover	Ears	WP
Soybean	<0	<0	<0	<0	<0	<0	4	<0	<0	8	<0	<0
Faba bean	>150	>150	>150	42	22	32	139	92	>150	37	44	41

^{z}Whole plants.

application; under conditions of N shortage, remobilisation of reduced N from vegetative parts (i.e., stover) after anthesis may be more important than under adequate N nutrition.

In 1988, at both locations, the DMY and N uptake of the stover, ears, and whole plants following faba bean were not influenced significantly by the N levels applied, except for the ear DMY at Deschambault; at St-Anselme, the N requirements of corn. were totally replaced following faba bean, and were replaced partly at Deschambault, as based on the respective DMY obtained without N application. In contrast, soybean as a previous crop did not contribute to the N requirements of corn at either location.

These differences can be attributable in part to a more significant N contribution from symbiotic N_2 fixation in faba bean compared with soybean, and the subsequent mineralization of this organic N from the residues. In a parallel study at both locations, Chalifour et al. (1990) reported that on average, the percentages of N derived from the atmosphere (Ndfa) in the aboveground biomass were 67.5% for faba bean and 47% for soybean at Deschambault; at St-Anselme, the percentages of Ndfa were 68% for faba bean and 57.5% for soybean. When taking into account grain harvesting, the amounts of Ndfa incorporated originating from stover would be approximately 75 kg N ha^{-1} for faba bean, and 6 kg N ha^{-1} for soybean at Deschambault; at St-Anselme, the estimates of Ndfa incorporated were 63 kg N ha^{-1} for faba bean, and 15 kg N ha^{-1} for soybean. With lower percentages of Ndfa in soybean than in faba bean, more N is taken up from soil and

harvested in the grain. Thus, the net N gain from faba bean cultivation was estimated at 51 kg N ha^{-1} at Deschambault, and at 41 kg N ha^{-1} at St-Anselme. Soybean led to a net N depletion estimated at 69 kg N ha^{-1} at both locations.

Our results for faba bean compare well with those of Senaratne and Hardarson (1988) who observed increased DMY of sorghum (Sorghum vulgare L.) and barley following incorporation of faba bean and pea (Pisum sativum L.) stover and/or roots. In their study, both legumes had positive effects on the soil N budget and subsequent nutrition (i.e., increased DMY and N uptake) of non-fixing cereal crops. The conservation of soil N by legume cultivation (i.e., less soil N taken up by legumes than by cereals) was also considered as a factor explaining the greater N uptake by cereals following legumes (Senaratne and Hardarson 1988). Fox and Piekielek (1988) also reported that corn succeeding to alfalfa (Medicago sativa L.), birdsfoot trefoil (Lotus corniculatus L.) and red clover (Trifolium pratense L.) took up more N than corn following corn and which received 0 or 54 kg N ha^{-1}. According to Barber (1972), the greater uptake of soil N can also arise due to better and deeper root growth of succeeding non-legume crops, as a result of improved soil properties by cultivation of forage legumes.

Without N application, the low DMY and N uptake of corn following soybean can be attributed to the low percentages of Ndfa in soybean, which resulted in little or no incorporation of fixed N_2, and depletion of soil N. In studies by Hesterman et al. (1986, 1987),

it was found that fixed N_2 originating from nodulated soybean and incorporated into the soil amounted to 15 kg N ha^{-1} at one site, and 17 kg N ha^{-1} at another site (Hesterman et al. 1987); the corresponding increases in grain yield were 14 and 84%, without N application. In addition, Hesterman et al. (1986) found no differences in the grain yields of corn which followed nodulated or non-nodulated soybean, within any level of N applied. Their results suggest that factors other than greater N availability following soybean cultivation may be responsible for the increased corn grain yields. In another study, Heichel and Barnes (1984) found that the N contribution of soybean residues was less than that expected; indeed, these authors found that the export of soil-derived N in the grain may substantially exceed that of symbiotically-derived N_2 in the residue that is returned to the soil; this confirmed that this legume grown for grain had little effect on the subsequent corn N requirements, as observed in our study. Our results also contrast with those of Gakale and Clegg (1987), who noted that without N application, sorghum following soybean yielded 85% more grain than continuous sorghum. In their study, however, the N supply following soybean cultivation was not as limiting as it appeared in our study, as indicated by increased residual soil N (as NO_3^--N) after soybean than after continuous sorghum production.

Baldock et al. (1981) defined the rotation effects (other than the N-rotation effect) as the yield differential between the cereal in monoculture and that following a legume at the highest N level. For some crop sequences (i.e., S-C at St-Anselme, and F-C and S-C at Deschambault, Fig. 2), the DMY of stover, ears, and whole plants of second-year corn reached a maximum at 100 kg N ha^{-1}, and decreased at 150 kg N ha^{-1}. Thus, there were definite rotation effects observed at the N level where maximum yields were observed (and not at the highest N level). This is particularly important for the S-C sequence at St-Anselme; rotation effects were only observed at the intermediate N levels (i.e., 50 and 100 kg N ha^{-1}), and led to the highest DMY

for whole plants at 100 kg N ha^{-1} that were similar to those for the F-C sequence. At Deschambault, corn from the S-C sequence also reached DMY similar to those for the F-C sequence at 100 kg N ha^{-1}. Rotation effects would have not been observable for soybean without N application, or at the highest N level.

The NFRV obtained for faba bean varied drastically between locations (Table 6), and illustrate the difficulty in recommending a range for the adjustment of N levels for forage corn production in a year following legumes. Similar observations (i.e., variation in NFRV among locations for the same legume) have been reported by Hesterman et al. (1986), who used alfalfa and soybean as first-phase crops. The NFRV obtained at Deschambault were lower than those obtained at St-Anselme, and may be due to different N mineralization potentials of the two soils; it may have been so high at Deschambault that the total rotational effects of faba bean were considerably reduced compared with St-Anselme. Indeed, at St-Anselme, N fertilization would have not been necessary for corn following faba bean, while at Deschambault, a substantial reduction in N fertilization would have been possible (see NFRV of faba bean, Table 6). At this latter site, corn grown in monoculture reached maximum DMY and N uptake at ca. 150 kg N ha^{-1}. On the other hand, NFRV values obtained for the F-C sequence suggest a reduction in fertilizer N ranging between 30 and 40 kg N ha^{-1} (whole plant data); this would mean that a N rate of ca. 110 kg N ha^{-1} (considering a maximum NFRV of 40 kg N ha^{-1}) would be sufficient for corn following faba bean at this site. The data show that the DMY and N uptake would be adequate at this N level (Figs. 2 and 3). If the optimal N requirement of hybrid Pioneer 3979 following 1 year of faba bean is considered to be 100 kg N ha^{-1}, then 70 kg N ha^{-1} would have been adequate for corn when it was preceded by faba bean at this site. The data for corn DMY and N uptake obtained at Deschambault (Figs. 2 and 3) certainly suggest that such a reduction in the N level applied (i.e., from

100 to 70 kg N ha^{-1}) would not affect yields significantly.

The estimation of the N-supplying potential of legumes to non-fixing crops by the NFRV method is certainly useful for crops having a positive impact on the soil N budget. However, it does not take into account other potential rotation effects such as those observed with soybean as a first-phase crop, particularly at St-Anselme. In addition, whereas the DMY of corn in monoculture generally reached maximum yields at 150 kg N ha^{-1}, the DMY of corn preceded by 1 year of either legume reached a maximum at 100 kg N ha^{-1} or less. Adjustment of N levels for corn production in rotation with legumes could contribute significantly to reducing production costs.

In conclusion, our data indicate that faba bean was more effective than soybean in reducing nitrogen requirements for forage corn the following year; this greater N contribution to corn by a previous faba bean crop is due in part to its positive impact on the soil N budget. At intermediate N levels, soybean was effective as a first-phase crop, in promoting higher DMY than corn as a first-phase crop; however, rotation effects due to soybean are presumably not linked to an increased N-supplying power. In addition to the N provided by faba bean to forage corn, evidence of rotation effects other than greater N availability were observed with faba bean, and, to a lesser extent, with soybean, particularly at St-Anselme. Proposed causes to explain rotation effects other than those related to increased N availability are quite diverse (Hesterman 1988). Factors that can explain the growth-promoting effects of previous legume crops on subsequent corn production are being investigated.

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