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Growing Soybean Prior to Corn Increased Soil Nitrogen Supply and N Fertilizer Efficiency for Corn in Cold and Humid Conditions of Eastern Canada

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Abstract

Growing soybean (*Glycine max L.)* prior to corn (*Zea mays* L) can enhance corn grain and nitrogen (N) use efficiency compared to continuous corn. This two year study (2007-2008) was conducted at 62 sites in Quebec (Eastern Canada) to assess the effect of crop rotations [soybean-corn, soybean-wheat (*Triticum aestivum* L.,)-corn and corn-corn] on corn yield, N uptake, N fertilizer efficiency (NFE), and the economic optimum N rate (EONR). Plots within each crop rotation received N fertilizer rates from 0 to 250 kg N ha^{-1} to assess the N contribution from the preceding soybean crop. Corn grain yields ranged from 8.4 to 10.8 Mg ha^{-1} and were lower in continuous corn than in the crop rotations. Corn N uptake and NFE varied from 89 to 164 kg N ha^{-1} and from 45 to 80 kg grain per kg N fertilizer, respectively. A significant interaction of crop rotation and year on corn N uptake and NFE was obtained implying that annual variations influenced soil N supply. The EONR for corn was lower under crop rotations than continuous corn in 2008 only. No difference in corn yield, NFE and EONR was observed for soybean-corn and soybean-wheat-corn crop sequences. In conclusion, crop rotations including soybean increased soil N availability and reduced EONR from 32 to 45 kg ha^{-1} for corn grown in 2008.

Keywords: corn yields and N nutrition, crop rotation, N credit, N fertilizer efficiency, economic optimum N rate

Abbreviations: NFE, N fertilizer efficiency; EONR, economic optimum N rate; PSNT, soil nitrate concentration at the corn six leaf growth stage; OC, organic carbon; TN, total nitrogen.

1. Introduction

Corn is among the most important crops in North America and in the world and is also the most nitrogen (N) fertilizer demanding crop. As the cost of N fertilizer is constantly rising, producers are searching for better N management practices that will enhance N fertilizer efficiency and will need to consider the soil N supply. Crops obtain N from biological N_2 fixation, previous manure applications and crop N residues, and from soil organic matter mineralization (Wortmann et al. (2011). Smil (1999) showed that 46% of the N input for crop production was derived from biological N_2 fixation, animal manures and crop residues. In a long-term study with N fertilizer and dairy cattle manure, Nyiraneza, Chantigny, N'Dayegamiye, & Laverdière (2010a) reported that N derived from soil contributed as much as 76% of total silage corn N nutrition, providing up to 208 kg N ha^{-1} in a corn-forage rotation that received 28 yrs of manure application at 20 Mg ha^{-1} year^{-1}.

Soil N supply and N use efficiency by corn may be enhanced in crop rotations that include legumes (Dobermann & Cassman, 2002). Corn is commonly rotated with soybean in northern regions of the United States and Canada, and benefits in corn productivity following soybean were reported. In a 4-yr study in Wisconsin, Bundy, Andraski & Wolkowski (1993) reported that corn grain yields were 5 to 30% higher and corn N uptake was significantly greater in a soybean-corn rotation than in continuous corn, over a range of N fertilizer inputs (0 to

225 kg N ha^{-1}). In western Canada, Wright (1990) reported that cereal yield was increased by 21% in the first year and 12% in the second year following legumes in the rotation.

Nitrogen credit from soybean was estimated to be roughly 45 kg N ha^{-1} in USA (Bundy et al., 1993). Varvel & Wilhelm (2003) reported higher soybean N credit for irrigated corn in Nebraska (65 kg N ha^{-1}) whereas Bergerou, Gentry, David & Below (2004) reported mean N input from soybean of 83 kg N ha^{-1}. Other studies reported that soybean N credit varies from year to year and it is influenced by factors such as soil type, climatic conditions (Oberle & Keeney, 1990; Bundy et al., 1993; Vanotti, Bundy, & Peterson, 1995), soil moisture and water use efficiency (Bergerou et al., 2003; Pikul, Hammack, & Riedell, 2005) and cropping history (Hesterman, Sheaffer, Barnes, Lueschen & Ford, 1986; Gentry, Below, David, & Bergerou 2001).

The N credit from soybean may be lower in humid, cool climates like Quebec because the N supply derived from soybean residues mineralization may not occur in synchrony with the peak N demand in corn. The provincial fertilizer guidelines suggest that soybean residues (non-harvested components and roots) contribute 25 kg N ha^{-1} to the subsequent crop in the rotation (CRAAQ, 2010). However, Paré, Challifour, Bourassa & Antoun (1993) reported the N fertilizer replacement value of soybean to be lower or equal to 0 kg N ha^{-1} based on data from 2 sites situated in cool humid conditions of Quebec, Eastern Canada. In major corn-growing regions of Quebec, Canada, the daily temperature starts decreasing to 10 ^{o}C in late September reaching 5 ^{o}C by the end of October. Average temperature during winter is between -10 and -25^{o}C. On average, the temperature in early spring (April to May) is 10 to 15^{o}C. These cool temperatures from late fall to early spring might slow decomposition rate of soybean residues and thus reduce the N supply to the following crops. This suggests that there is a need to conduct more extensive site-specific studies in humid and cool climate of Eastern Canada to assess real soybean N contributions to the following corn crop. There is also a lack of information on the soybean N credit to corn one or two years after the last introduction of soybean in the rotations.

The objectives of this study were to evaluate how crop rotations with soybean affect production of the following corn crop, based on corn yield, N uptake, N fertilizer efficiency and economic optimum N rate. The crop sequences studied were soybean-corn, soybean-wheat-corn and continuous corn, which served as the experimental control. The study was conducted at 62 fields across Quebec to take into account a broad range of soil types and climatic conditions.

2. Materials and Methods

2.1 Site Description and Experimental Design

This research was conducted on 30 sites and 32 sites in 2007 and 2008, respectively, in fields located in 7 regions of Québec (Eastern Canada). The sites sampled in 2007 were different from those sampled in 2008, although situated in the same region. There was also seasonal variation, with more rainfall during the 2008 growing season than in 2007, especially during June and July (Nyiraneza et al., 2010). Studied sites showed a broad range of soil properties in both years. The coefficient of variation was of 36%, 9%, 31%, 29%, 66%, 85% and 61% for clay, pH, total N, PSNT, Mehlich-3-P, and Mehlich-3-K, respectively in 2007, and was of 49%, 7%, 40%, 39%, 66%, 57% and l9% , respectively in 2008 (Tables 1 and 2). Soil texture at the sites was sandy loam, loam and clay loam. However, clay loam soils were predominant.

Each year, the study was conducted on fields with different crop rotations: soybean-corn, soybean-wheat corn and corn-corn crop sequence. Details of the experimental design were described by Nyiraneza et al. (2010). Briefly, a complete block design was established at each site and consisted of six N treatments (0, 50, 100, 150, 200, and 250 kg N ha^{-1}) replicated 3 times. Each plot (experimental unit) was 10- to 12-m long and 3-m wide. Therefore, the experimental unit consisted of 4 rows with 0.75-m row spacing. Nitrogen was applied as calcium ammonium nitrate (27% N) and was split-applied in two fractions: the first 50 kg N ha^{-1} as a starter and the remaining fraction at the six leaf (V_6) growth stage. Phosphorus and potassium fertilizers were applied at planting at rates of 50 kg P and 75 kg K ha^{-1} as triple superphosphate and potassium chloride, respectively. Corn populations ranged from 86,000 to 88,000 plants ha^{-1}. The harvest started on October 15th and ended by November 5th in both years. Corn grain yields were determined by harvesting the two central rows from each plot. Whole plants were cut at the soil surface, chopped and weighed. Subsamples of plant tissue or grain (about 800 g) were taken and dried at 65° C to a constant mass to determine dry matter, followed by total N analysis with micro-Kjeldhal digestion (Bremner, 1965) for determination of total N concentration on an automated colorimeter (Technicon Instruments, Tarrytown, NY). Corn N uptake (kg N ha^{-1}) in the whole plant (plant tissue and grain) was summed after calculating the product of the N concentration and dry matter yield of each component. For each fertilizer N treatment, the NFE was determined as described by Wortman et al. (2011):

N fertilizer efficiency (kg grain kg^{-1} N fertilizer) = (Yield for N treatment-Yield for control treatment)/N fertilizer rate.

Table 1. Soil properties at field sites in Quebec under corn production in 2007 following continuous corn, soybean-corn or soybean-wheat- corn rotations

Location	Clay	pH	Org.	Total N	†PSNT	Melhich-3-P	Melhich-3-K
	g kg^{-1}		g kg^{-1}		mg kg^{-1}		
Crop rotation : corn- corn							
Deslauriers	370	6.7	15.6	1.36	6.22	45	144
IRDA field 10	370	6.2	9.5	0.87	5.55	59	175
CEROM	680	7.4	30.2	2.43	8.33	65	462
Jojo	370	6.3	18.9	1.40	38.23	75	264
Bonneterre	360	6.4	30.2	2.61	7.74	29	103
Tourigny	360	7.4	17.8	1.55	7.34	42	121
IRDA D6-2	120	5.7	16.2	1.11	3.96	380	68
IRDA 58A	280	5.9	24.9	1.78	2.75	37	358
IRDA 58C	250	6.9	12.8	1.19	7.54	42	112
IRDA 58D	250	6.8	11.1	0.88	5.06	34	65
IRDA -Mono	320	6.3	29.2	1.75	7.17	185	146
IRDA-Rota2	300	6.4	26.5	2.02	11.58	61	63
IRDA- Rota3	260	6.6	25.8	1.72	8.09	107	188
IRDA-Rota4	290	5.9	25.8	1.92	14.33	50	71
Minimum	120	5.7	9.5	0.87	2.75	29	63
Maximum	680	7.4	30.2	2.61	38.23	380	462
Mean	327	6.5	21	1.61	9.56	86	167
Crop rotation : soybean-corn							
Gfeller	340	7.5	26.5	2.36	8.63	49	86
Lamoureux	290	6.9	24.2	1.92	8.62	47	87
Lamoureux B	230	7.2	21.1	1.40	11.63	50	94
Landry	180	6.2	13.3	1.09	12.97	81	120
Riendeau	520	7.6	21.1	1.76	6.19	57	206
Hélyon	340	6.9	13.5	1.24	8.99	79	160
Hamel	210	7.0	20.9	1.60	10.59	231	132
Guilbert	430	7.8	27.3	2.23	8.68	130	363
Bonneterre	310	6.0	15.6	1.38	21.47	41	153
Minimum	180	6.0	13.3	1.09	6.19	41	86
Maximum	520	7.8	27.3	2.36	21.47	231	363
Mean	316	7.0	20.4	1.66	10.86	85	156
Crop rotation: soybean-wheat-corn							
Bernard	360	6.9	21.6	1.85	10.52	58	178
IRDA, field 8	340	6.3	11.7	0.97	5.62	56	184
Roch	200	6.4	22.4	1.45	18.20	83	114
CIEL	250	6.7	16.9	1.58	12.16	152	179
Amiénoise	220	5.5	13.6	1.11	11.90	68	148
IRDA D2-2	120	5.8	15.6	1.30	24.14	88	52
Minimum	120	5.5	11.7	0.97	5.62	56	52
Maximum	360	6.9	22.4	1.85	24.14	152	184
Mean	248	6.3	16.9	1.37	13.7	84	142

† In-season soil nitrate concentration from plots that did not receive N fertilizer

Table 2. Soil properties at field sites in Quebec under corn production in 2008 following continuous corn, soybean-corn or soybean-wheat-corn rotations

Locations	Clay g kg^{-1}	pH	Org. C g kg^{-1}	Total N	†PSNT mg kg^{-1}	Melhich-3-P	Melhich-3-K
Crop rotation: corn-corn							
Landry	330	7.2	15.3	1.3	1.99	74	151
Huot	560	6.8	11.7	1.25	6.23	19	177
IRDA field 15	170	6.7	7.4	0.68	3.59	119	88
IRDA field 10	310	6.3	9.8	1.01	3.76	50	171
IRDA field 8	320	6.5	9.2	0.91	3.68	37	148
Roch	460	6.1	17.6	1.69	11.80	16	163
Tourigny	80	6.4	18.2	1.43	11.17	48	56
IRDA D3-2	130	5.9	16.6	1.44	2.68	90	65
IRDA-58A	310	5.8	24.8	1.9	7.70	29	355
IRDA -58C	270	6.8	12.0	1.2	6.81	36	89
IRDA-58D	210	6.5	14.0	1.29	3.81	30	59
IRDA-Mono	320	6.4	26.6	1.79	4.77	142	136
IRDA-Rota2	270	6.1	19.6	1.97	9.79	26	67
IRDA-Rota3	290	6.4	27.3	1.9	6.41	25	33
Minimum	80	5.8	7.4	0.68	1.99	16	33
Maximum	560	8.2	27.3	1.97	11.8	142	355
Mean	288	6.4	16.4	1.4	6.0	53	125
Crop rotation : soybean-corn							
Lamoureux	230	5.3	16.8	1.51	5.28	53	159
Lamoureux B.	260	6.8	15.5	1.47	1.57	33	55
Dumesnil	210	7.1	27.7	2.38	6.36	42	55
CEROM	560	7.5	28.2	2.48	10.05	56	433
Hélyon	230	6.3	11.7	1.16	10.68	68	117
Pagé	400	6.8	15.6	1.3	6.87	50	175
Bonneterre	370	6.6	19.7	1.88	9.29	57	149
Enright	230	7.1	35.3	3.52	23.27	14	47
Minimum	210	5.3	11.7	1.16	1.57	14	47
Maximum	560	7.5	35.3	3.52	23.27	68	433
Mean	311	6.7	21.3	1.9	9.2	46.6	148.7
Crop rotation : soybean-wheat-corn							
Letellier	39	6.7	17.4	1.66	8.25	61	148
Deslauriers	360	7.3	33.1	2.78	4.45	126	218
Dubuc	640	6.4	19.9	2.47	5.50	38	301
CIEL	250	6.7	14.6	1.53	9.75	48	148
Lafortune	540	6.5	17.0	1.69	5.59	52	326
Amiénoise	160	7.4	13.0	1.03	10.05	56	97
Paré	220	7.0	25.4	2.3	21.47	48	86
IRDA D3-3	110	5.9	6.1	0.62	2.19	62	72
Minimum	39	5.9	6.1	0.62	2.19	38	72
Maximum	640	7.4	33.1	2.78	21.47	126	326
Mean	289.9	6.7	18.3	1.76	8.4	61.4	174

† In-season soil nitrates from plots that did not receive N fertilizer

2.2 Statistical Analysis

Detailed analysis of nitrogen response functions and EONR calculation were given by Nyiraneza et al. (2010). Data on corn yields, N uptake, and N fertilizer efficiency were analyzed for each experimental field separately and analysis of variance was performed using PROC MIXED of SAS (SAS Institute, 2003). The fixed effects were N fertilizer rates and the random effects were the blocks. When the N fertilizer was significant, contrast analysis were used to assess if the effect was linear or quadratic. Next, sites with the same crop rotations were grouped together and the mean values of corn yield, N uptake, NFE and EONR were calculated. The EONR values were reported by Nyiraneza et al. (2010).

The analysis of variance of the effects of previous crop and year on the response variables was performed using PROC MIXED procedure of SAS, version 9.1 (Littell, Milliken, Stroup, Wolfinger & Schabenberger, 2006). The statistical linear model includes the fixed effects of previous crop, year and interaction of previous crop × year. Year was considered as a fixed effect because different weather conditions occurred in 2007 and 2008 and inference for each year is needed. It is assumed that the various sites were independent and generated random variation on the response variable, with normal distribution of mean 0 and variance σ^2. Normality and homogeneity assumptions were checked with an analysis of residuals. Analysis of N uptake and NFE displayed unequal variances among combinations of previous crop x year. Therefore, a model with a different variance for each combination was fitted using the option GROUP = previous crop×year in the REPEATED statement of PROC MIXED. Degrees of freedom (DF) were estimated with the Satterthwaite approximation, which explains the non integer values for DF. Since the interaction of previous crop x year was significant, adjusted means based on model were calculated for each previous crop x year combination using LSMEANS statement. Unequal group sizes were also accounted for in the calculations of standard errors. Pairwise comparisons among the three crop rotations were made for each year.

3. Results and Discussion

3.1 Soil Properties

Although the study was conducted in fields with diverse soil texture and historical management each year, the mean values for pH, organic C, total N and Mehlich-3 extractable P and K were comparable among different crop rotations (Tables 1 and 2). Analysis of variance showed no effect of crop rotation on the in-season soil nitrate concentration at the corn V6 growth stage (PSNT, data not reported). We expected higher values of PSNT in soil where soybean was included in the rotation, but the soil conditions (cold, humid soils) may have slowed organic N mineralization from soybean residues such that there was no evident increase in the soil N supply early in the growing season, around mid-June. The effect of previous crop on corn yield and N nutrition is associated with soil characteristics, year and climatic conditions (Bundy et al., 1993; Bergerou et al., 2004) which influence N mineralization. Oberle & Keeney (1990) reported that effects of including soybean in a crop sequence on N availability were largely affected by soil type and the frequency of legumes in the rotation. Corn N uptake from previous soybean was lower in sandy soils than in silt loam soils (Bundy et al., 1993). Most of the soils in this study are loamy to clay soils (Tables 1 and 2) which probably slowed the mineralization of organic N from soybean residues.

3.2 Effect of Crop Rotation on Corn Yields and N Uptake

Corn N response to fertilizer N application was significant at most studied locations and there was a quadratic response for corn yield, N uptake, and NFE (Table 3). Previous analysis of these sites showed that corn N fertilizer response was best described by a quadratic-plus plateau model (Nyiraneza et al., 2010).

Table 3. Effects of N fertilizer applications on corn grain yield, N uptake, and N fertilizer efficiency (NFE) in 2007 and 2008. Field sites were in Quebec and are described in Tables 1 and 2.

2007				2008			
Location	Yield Mg ha^{-1}	N uptake kg ha^{-1}	NFE kg grain kg N^{-1}	Locations	Yield Mg ha^{-1}	N uptake kg ha^{-1}	NFE kg grain kg N^{-1}
Crop rotation: corn-corn							
Deslauriers	†10.8±	142±	81±	Landry	9.2±	90+	46+
IRDA	12.8±	169±	117±	Huot	10.9±	118+	65±
CEROM	10.2+	145+	81±	IRDA-15	10.8±	106±	67±
Jojo	9.4	171	65±	IRDA-10	11.4+	112	69±
Bonneterre	10.4±	160±	69±	IRDA-8	12.4+	96±	57±
Tourigny	11.0±	130+	75±	Roch	7.7+	130±	60±

IRDA D6-2	9.0+	95+	63+	Tourigny	8.4±	130±	71±
IRDA 58A	9.1±	148+	90±	Deschambault3-2	5.2±	71+	40±
IRDA 58C	9.5±	134+	79±	IRDA-58C	4.1+	44+	21+
IRDA 58D	7.0±	85±	43±	IRDA -58C	5.3+	67+	34
IRDA -Mono	6.9±	90±	47+	IRDA-58D	3.9+	55+	20
IRDA-Rota2	7.5±	130+	71±	IRDA-Mono	3.2+	47+	13+
IRDA- Rota3	7.9+	113+	58+	IRDA-Rota2	5.2	126+	45
IRDA-Rota4	7.6±	138±	75±	IRDA-Rota3	3.0	61+	20+
Crop rotation : soybean-corn							
Gfeller	11.5±	154±	88±	Lamoureux	10.7±	128±	80±
Lamoureux	11.6±	127+	76+	Lamoureux B.	10.0+	129+	73±
Lamoureux B	10.3±	88±	57±	Dumesnil	9.5+	93±	72±
Landry	11.6±	188±	102±	CEROM	10.6±	154+	91+
Riendeau	8.5±	123+	62±	Hélyon	10.1±	174±	86±
Hélyon	11.9±	144+	84±	Pagé	9.5±	147+	67±
Hamel	11.7±	151±	89±	Bonneterre	9.3±	164+	73±
Guilbert	10.8+	132+	73±	Enright	8.4+	171±	68±
Bonneterre	10.2±	139±	64±				
Crop rotation: soybean-wheat-corn							
Bernard	10.8±	192±	96±	Letellier	11.4+	142+	71+
IRDA. field 8	13.3±	129±	94+	Deslauriers	12.7+	145+	51+
Roch	9.5±	167+	67±	Dubuc	11.2±	139±	86±
CIEL	12.2+	217±	102±	CIEL	10.6±	190+	87+
Amiénoise	12.3±	181+	121±	Lafortune	9.3±	133±	67±
IRDA D2-2	9.0±	99+	65+	Amiénoise	10.1±	156±	81±
				Paré	6.9±	153+	54+
				IRDA D3-3	6.3±	62±	40+

†Means values

+. ±: linear, and quadratic effects of N fertilizer, respectively

Analysis of variance showed that corn yield was influenced significantly by crop rotation and year (Table 4). Averaged across sites and years, corn yields ranged from 8.4 to 10.8 Mg ha^{-1} and were 30% lower for corn following corn, than crop rotations that included soybean (Figure 1). This finding is consistent with results in other regions of North America where corn is intensively grown (Baldock, Higgs, Paulson, Jackobs & Shrader, 1981; Power, Doran & Wilhelm, 1986; Crookston, Kurle, Copeland, Ford, & Lueschchen, 1991; Rembon & and MacKenzie, 1997; Grover, Karsten, & Roth, 2009; Dobermann et al., 2011). We have noticed that corn yield in the soybean-corn sequence was not significantly different to that of soybean-wheat-corn sequence (Figure 1). This could imply slow release of N from soybean residues over a two-yr period or it could be due to other benefits of crop rotation such as the soil physical condition improvement.

Table 4. Analysis of variance of the effects of previous crop and year on corn yield, N uptake, NFE and EONR. The number of field sites in each crop rotation sequence in 2007 and 2008 are given in Tables 1 and 2.

†Source of variation	Yield	N uptake	Fertilizer N efficiency	Economic optimum N rate
(F value)				
Previous crop	7.50**	9.76***	7.53**	3.09*
Year	4.53*	5.47*	4.03	4.04*
Previous crop x year	0.34	3.23*	4.03*	2.19

Means values per site of each parameter obtained from sites under the same crop rotation sequence were used.

* ,** ,***: significant at P<0.05, P<0.01, and P<0.001, respectively.

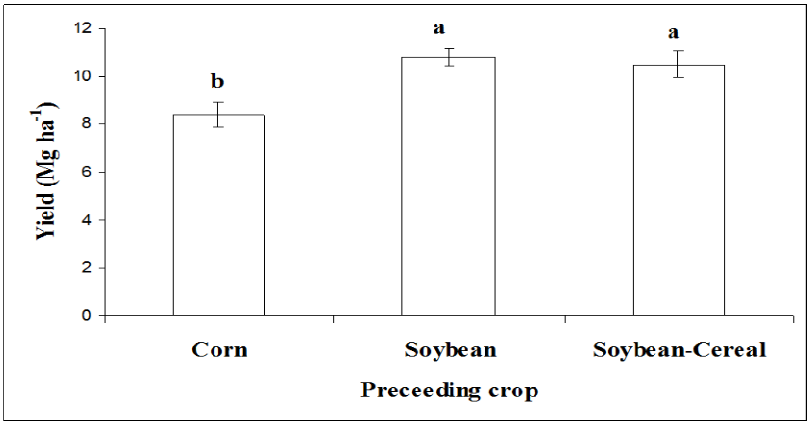

Figure 1. Corn yield data averaged across sites and year in function of previous crop rotations

Vertical barsrepresent standard error of the mean. Bars followed by different letters are statistically different at 0.05 probability level. Means values of corn yield obtained from sites under the same crop rotation sequence were used.

There is good evidence for N recycling from soybean residues that contributed to the corn N nutrition. Corn N uptake ranged from 89 to 164 kg N ha^{-1} (Figure 2I) and an average increase of 28 and 37% was found when soybean was a preceding crop (soybean-corn or soybean-wheat-corn, respectively) compared to continuous corn. Analysis of variance (Table 4) showed a significant effect of previous crops, year and a significant interaction of previous crops and year on corn N uptake. Our results are in line with previous studies where it was shown that crop sequence with soybean increased corn N uptake in comparison with corn following corn (Baldock et al., 1981; Bundy et al., 1993, Rembon & MacKenzie, 1997). On average, N credit from soybean varied from 31 to 42 kg N ha^{-1} (Figure 2I) and the lower range value is close to that (25 kg N ha^{-1}) reported in Québec (CRAAQ, 2010). With respect to previous studies**,** higher soybean N credits were found by Varvel & Wilhelm (2003) for irrigated corn in Nebraska (65 kg N ha^{-1}) whereas Bergerou et al. (2004) reported N credit from soybean of 83 kg N ha^{-1} in Illinois. The legume N credit is expected to be higher in warmer climatic conditions than in the cold, humid region of Eastern Canada due to higher soybean yield and thus higher residue inputs (Crookson et al. 1991). Mean soybean yields is around 3 Mg ha^{-1} in Québec (Canada) (N'Dayegamiye, 2009), lower than those in Midwest of the United States (3 to 5 Mg ha^{-1}) and this may explain higher soil N credit from soybean residues in warmer areas.

The effect of previous crop on corn yield and N nutrition is associated with soil characteristics, year and climatic conditions (Bundy et al., 1993; Bergerou et al., 2004) which influence N mineralization. Oberle and Keeney (1990) reported that effects of including soybean in a crop sequence on N availability were largely affected by soil type and the frequency of this legume in the rotation. Corn N uptake from previous soybean was lower in sandy soils than in silt loam soils (Bundy et al., 1993). Most of the soils in this study are loamy to clay soils (Tables 1 and 2) which probably slowed the mineralization of organic N from soybean residues.

3.3 Effect of Crop Rotation on Corn N Fertilizer Efficiency (NFE)

Crop sequence effect on N fertilizer efficiency was significant as well as the interaction between year and crop sequence (Table 4). In this study, NFE varied from 44,8 to 76.7 kg grain kg N^{-1} (Figure 2B). In 2008, N efficiency in corn-corn sequence was significantly lower than in soybean-corn or soybean-wheat-corn sequences (Figure 2B). This finding is also in line with recent work by Pikul et al. (2005) and Wortmann et al. (2011) who showed that crop rotation sequence including drybean (*Phaseolus vulgaris* L.) and soybean had higher fertilizer N efficiency compared to corn following corn. Corn N fertilizer efficiency (NFE) or grain production per unit of applied N fertilizer is merely influenced by the efficiency of N uptake by the crop and the conversion of total N to grain (Moll, Kamprath, & Jackson, 1982) and this would change with annual climatic variations, which probably explain the interaction between year and crop sequence effect on NFE in our study.

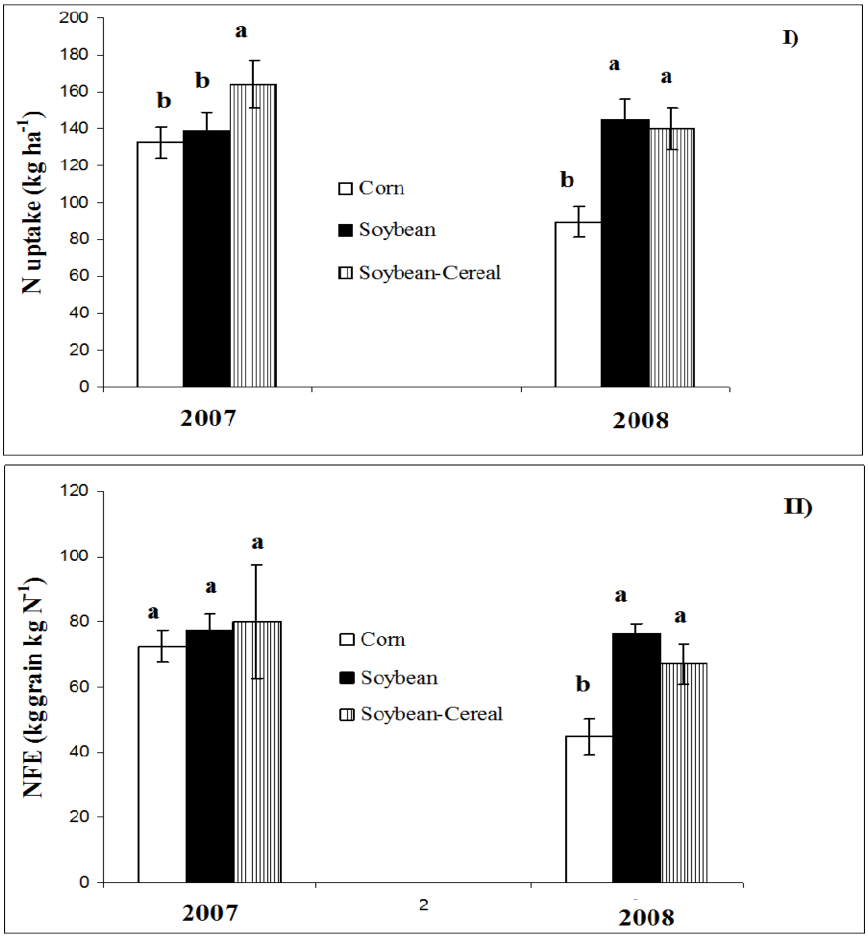

Figure 2. Effects of previous crop on corn N uptake (I), and N fertilizer efficiency (II)

Vertical bars represent standard error of the mean. Bars followed by different letters are statistically different at 0.05 probability level. Means values of corn N uptake and NFE obtained from sites under the same crop rotation sequence were used.

3.4 Effect of Crop Rotation on Corn Economic Optimum N Rate (EONR)

The EONR was affected significantly by the previous crop and year of study (Table 4), with EONR values between 154 and 214 kg N ha^{-1} (Figure 3). The EONR was lower in crop sequences that included soybean, compared to corn following corn in 2008 (154 kg N ha^{-1}) but not in 2007. The effect of the preceding soybean crop for corn was variable with year, apparently related to mineralization and availability of organic N from residues as affected by climatic conditions. This observation is consistent with results obtained in several other studies (Nafziger, Mulvaney, Mulvaney, & Paul, 1984; Gentry et al., 2001; Stanger & Lauer, 2008) and suggests that corn N recommendation rate can be reduced when following soybean and soybean-wheat rotation sequences.

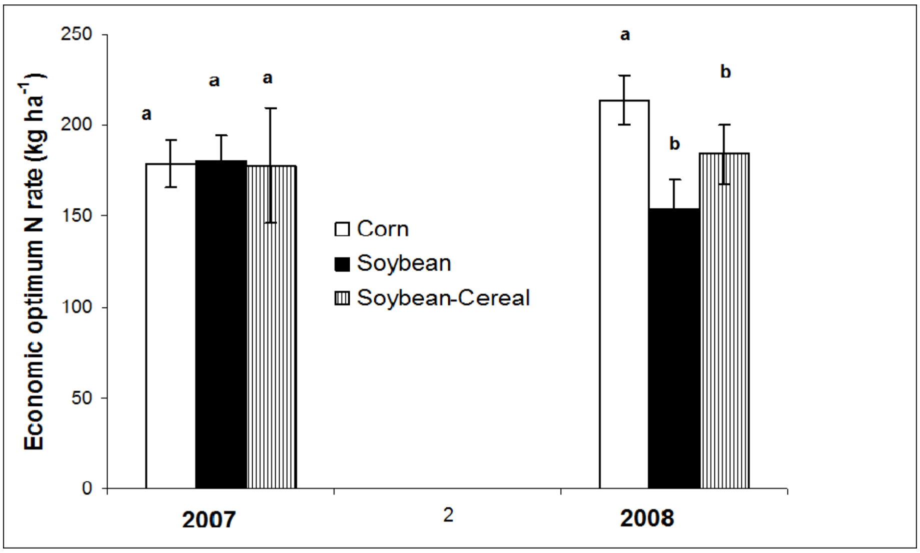

Figure 3. Effects of previous crop on economic optimum N rate

Vertical bars represent standard error of the mean. Bars followed by different letters are statistically different at 0.05 probability level. Means EONR values obtained from sites under the same crop rotation sequence were used.

In summary, results from this study conducted on 62 sites in Quebec (Eastern Canada) showed that there was greater N uptake and fertilizer efficiency and lower EONR in corn grown one or two years after soybean, compared to corn-corn rotation. Calculated N credit from soybean was from 31 to 42 kg N ha^{-1} in our study and is in the range of the current soybean N credit value of 25 kg N ha^{-1} in Quebec guideline (CRAAQ, 2010) and the soybean N credit of 45 kg N ha^{-1} used widely in USA (Kurtz, Bone, Peck, & Haaf, 1984). Including soybean in the rotation once every two years or every three years did not make any difference and this presumably suggests that an important part of soybean N mineralized from its residues was still available two years after their incorporation into the soil. Therefore, N supplied by soybean residues are partially used in the following year with cereal, and is still available in the second year for corn. This is in contradiction with the study conducted in Nebraska by Power et al. (1986) who showed that mineralization of organic N in soybean is rapid. The beneficial long lasting effect of soybean residues evidences that mineralization of organic soybean residues is low in wet and cold climate regions of Eastern Canada.

This study demonstrated that in 2008, EONR was lower in crop rotation including soybean than in continuous corn and yet any significant effect of crop rotation was observed on measured soil nitrates at corn V6 (six leaves) growth stage (PSNT). The PSNT values were similar in all plots but more N uptake was observed in the soybean-corn and soybean-wheat-corn rotation sequence than in corn-corn in 2007 and 2008. These results suggest that the soil N gets released later in the growing season after the V6 corn growth stage and then corn absorbed it. In addition, improved soil physical properties such as soil aggregation, soil moisture, water use efficiency and soil N mineralization (Gentry et al., 2001; Bergerou et al., 2004; Pikul et al., 2005) could have boosted corn N uptake.

Nitrogen-related factors have been explained by the fact that corn residue decomposition is accompanied by an N immobilization whereas introduction of a legume increase residual N from symbiotic fixation (Gentry et al., 2001). Non-N related factors associated with crop rotations were explained by a combination of multiple factors such as reduced pest infestation which is associated with better root development, which in turn increases crop water use efficiency and nutrient cycling. Other studies reported benefits of crop rotation were: improved soil moisture; reduced weed, elimination of phytotoxic substances in corn residues (Barber, 1972). As stated by Baldock et al. (1981), it is more informative to assess potential effects of crop rotations rather than focusing on its potential causes. Regardless of the mechanism, our results indicate that including soybean in rotation with corn, whether it is one or two years prior to the corn production year, will boost yield, increase N uptake, NFE and reduce the EONR compared with continuous corn. The latter effect is however affected by year as we observed comparable values of EONR in 2007 whereas including soybean reduced EONR by an average of 45 kg N ha^{-1} compared to continuous corn in 2008.

This study shows that further studies are still necessary to study how fast soybean residue is mineralized in cold and humid soil conditions. Although it is well known that N related factors and non-N related factors are both responsible of benefits of crop rotations on the following crop yield, it is still a matter of debate to determine which factors predominate.

4. Conclusions

This study conducted on 62 sites of Quebec (eastern Canada) showed increased corn yield, N uptake and N fertilizer efficiency, and a decreased EONR in soybean-corn and soybean-wheat-corn- rotation systems compared with corn-corn. There was a significant effect of year on measured crop parameters, which implies that climatic conditions influence soil N supply from organic residues as well as crop growth and N uptake. During this 2yr-study, N credit from soybean varied from 31 to 42 kg N ha^{-1}. The soybean-corn and soybean-wheat-corn rotations were equally effective in boosting corn yield, NFE and reducing the EONR. In cold and humid regions of eastern Canada with slow decomposition of soybean residues, benefits of soybean to the following corn can last up to two years following the last introduction of soybean in the rotation.

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References

Baldock, J. O., Higgs, R. L., Paulson, W. H., Jackobs, J. A. , & Shrader, W. D. (1981). Legume and mineral N effects on crop yields in several crop sequences in the upper Mississipi Valley. *Agron. J., 73*, 885-890. http://dx.doi.org/10.2134/agronj1981.00021962007300050031x

Barber, S. A. (1972). Relation of weather to the influence of hay crops on subsequent corn yield on a Chalmers silt loam. *Agron. J, 64*, 8-10. http://dx.doi.org/10.2134/agronj1972.00021962006400010003x

Bergerou, J. A., Gentry, L. E., David, M. B., & Below, F. E. (2004). Role of N_2 fixation in the soybean N credit in maize production. *Plant and Soil, 262*, 383-394. http://dx.doi.org/10.1023/B:PLSO.0000037057.35160.ec

Bremner, J. M. (1965). Total nitrogen, inorganic forms of nitrogen. P. 1149-1255. *In* C.A. Black et al. (ed.). Methods of soil analysis. *Agron. J.* Monogr.9. Part 2. ASA. Madison. WI.

Bundy, L. G., Andraski, T. W., & Wolkowski, R. P. (1993). Nitrogen credits in soybean-corn crop sequence on three soils. *Agron. J, 85*, 1061-1067. http://dx.doi.org/10.2134/agronj1993.00021962008500050020x

CRAAQ. (2010). Centre de Reference en Agriculture et Agroalimentaire du Québec. *Fertilization reference guide* (In French). Sainte-Foy, Qc, Canada.

Crookston, R. K., Kurle, J. E., Copeland, P. J., Ford, J. H., & Lueschchen, W. E. (1991). Rotational cropping sequences affect yield of corn and soybean. *Agron. J., 83*, 108-113. http://dx.doi.org/10.2134/agronj1991.00021962008300010026x

Dobermann, A., & Cassman, K. G. (2002). Plant nutrient management for enhanced productivity in intensive grain production systems of the United States and Asia. *Plant Soil, 247*, 153-175. http://dx.doi.org/10.1023/A:1021197525875

Dobermann, A., Wortmann, C. S., Ferguson, R. B., Hergert, G. W., Shapiro C. A., Tarkalson, D. D., & Walters, D. T. (2011). Nitrogen response and economics for irrigated corn in Nebraska. *Agron. J., 103*, 67-75. http://dx.doi.org/10.2134/agronj2010.0179

Gentry, L. E., Below, F. E., David, M. B., & Bergerou, J. A. (2001). Source of the soybean N credit in maize production. *Plant and Soil, 236*, 175-184. http://dx.doi.org/10.1023/A:1012707617126

Grover, K. K., Karsten, H. D., & Roth, G. W. (2009). Corn grain yields and yield stability in four long-term cropping systems. *Agron., 101*, 940-946. http://dx.doi.org/10.2134/agronj2008.0221x

Hesterman, O. B., Sheaffer, C. C., Barnes, D. K., Lueschen, W. E., & Ford, J. H. (1986). Alfalfa dry matter production, and fertilizer nitrogen response in legume-corn rotations. *Agron. J, 78*, 19-23. http://dx.doi.org/10.2134/agronj1986.00021962007800010005x

Kurtz, L. T., Bone, L. V., Peck, T. R., & Haaf, R. G. (1984). Crop rotations for efficient nitrogen use. P. 295-306. In *Nitrogen in crop production*. R.D. Hauck (ed.). Am. Soc. Agron. Madison, WI

Littell, R. C., Milliken, G. A., Stroup, W. W., Wolfinger, R. D., & Schabenberger, O (2006). SAS for Mixed Models, Second Edition. Cary, NC : SAS Institute Inc., 2006. ISBN-13: 978-1-59047-500-3

Moll, R. H., Kamprath, E. J., & Jackson, W. A. (1982). Analysis and interpretation of factors which contribute to efficiency to nitrogen utilization. *Agron. J., 74*, 562-564. http://dx.doi.org/10.2134/agronj1982.00021962007400030037x

Nafziger, E. D., Mulvaney, R. L. Mulvaney, D. L., & Paul, L. E. (1984). Effect of previous crop on the response of corn to fertilizer nitrogen. *J. Fert. Issues, 1*, 136-138.

N'Dayegamiye, A. (2009). Soil Properties and Crop Yields in Response to Mixed Paper Mill Sludges, Dairy Cattle Manure, and Inorganic Fertilizer Application. *Agron. J., 101*, 826-835. http://dx.doi.org/10.2134/agronj2008.0170x

Nyiraneza, J., Chantigny, M. H., N'Dayegamiye, A., & Laverdière, M. R. (2010a). Long-term manure application and forages reduce nitrogen fertilizer requirements of silage corn-cereal cropping systems. *Agr. J, 102*, 1244-1251. http://dx.doi.org/10.2134/agronj2009.0480

Nyiraneza, J., N'Dayegamiye A., Gassser, M. O., Giroux, M., Grenier, M., Landry, C., & Guertin, S. (2010b). Soil and crop parameters related to corn nitrogen response in Eastern Canada. *Agron. J., 102*, 1478-1490. http://dx.doi.org/10.2134/agronj2009.0458

Oberle, S. L., & Keeney, D. R. (1990). Factors influencing corn fertilizer N requirements in the Northern U.S. Corn Belt. *J. Prod. Agric, 3*, 527-534.

Paré, T., Challifour, F. P., Bourassa, J., & Antoun, H. (1993). Forage-corn production and N fertilizer replacement values following one or two years of legumes. *Can. J. Plant Sci*., *72*, 699-712. http://dx.doi.org/10.4141/cjps93-066

Pikul, Jr, Hammack, J. L., & Riedell, W. E. (2005). Corn yield, nitrogen use, and corn rootworm infestation of rotations in the northern Corn Belt. *Agron. J., 97*, 854-863. http://dx.doi.org/10.2134/agronj2004.0263

Power, J. F., Doran, J. W., & Wilhelm. W. W. (1986). Uptake of nitrogen from soil, fertilizer, and crop residue by no-till corn and soybean. *Soil Sci. Soc. Am. J., 50*, 137-142. http://dx.doi.org/10.2136/sssaj1986.03615995005000010027x

Rembon, F. S., & MacKenzie, A. F. (1997). Soybean nitrogen contribution to corn and residual nitrate under conventional tillage and no-till. *Can. J. Soil Sci*., *77*, 543-551. http://dx.doi.org/10.4141/S96-096

SAS Institute. (2003). *SAS user,s guide. Statistics*. Version 9.2. SAS Inst., Cary, NC.

Smil, V. (1999). Nitrogen in crop production. An account of global flows. *Global Biogeochem. Cycles, 13*, 647-662. http://dx.doi.org/10.1029/1999GB900015

Stanger, T. F., & Lauer, J. G. (2008). Corn grain yield response to crop rotation and nitrogen over 35 years. *Agron. J., 100*, 643-650. http://dx.doi.org/10.2134/agronj2007.0280

Vanotti, M. B., Bundy, L. G., & Peterson, A. E. (1995). Nitrogen fertilizer and legume-cereal rotation effects on soil productivity and organic matter dynamics in Wisconsin. In E.A. PUL ET AL. (ED) *Soil organic matter in the long-term plots of North America*. Lewis Publ., Chelsea, MI.

Varvel, G. E., & Wilhelm, W. W. (2003). Soybean nitrogen contribution to corn and sorghum in western Corn Belt rotations. *Agron. J., 95*, 1220-1225. http://dx.doi.org/10.2134/agronj2003.1220

Wortmann, C. S., Tarkalson, D. D., Shapiro, C. A., Dobermann, A. R., Ferguson, R. R., Hegert, G. W., & Waters, D. (2011). Nitrogen use efficiency of irrigated corn for three cropping systems in Nebraska. *Agron. J., 103*, 76-84. http://dx.doi.org/10.2134/agronj2010.0189

Wright, A. T. (1990). Yield effect of pulses on subsequent cereal crops in the northern prairies. *Can. J. Plant Sci., 70*, 1023-1032. http://dx.doi.org/10.4141/cjps90-125