ORDER REPRINT

JOURNAL OF PLANT NUTRITION
Vol. 26, No. 7, pp. 1383–1402, 2003

Previous Corn Row Effects on Potassium Nutrition and Yield of Subsequent No-Till Soybeans

Xinhua Yin and Tony J. Vyn*

Department of Agronomy, Purdue University,
West Lafayette, Indiana, USA

ABSTRACT

Narrow-row soybean [*Glycine max* (L.) Merr.] production in corn [*Zea mays* L.]–soybean rotations results in various distances of soybean rows from previous corn rows, yet little is known about soybean responses to proximity to prior corn rows in no-till systems. The objective of this study was to evaluate the impacts of preceding corn rows on potassium (K) nutrition and yield of subsequent no-till soybeans. Four field experiments involving a corn–soybean rotation were conducted on long-term no-till fields with low to medium K levels from 1998 to 2000 near Paris and Kirkton, Ontario, Canada. In the corn year, treatments included K application rate and placement in conjunction with tillage systems or corn hybrids. Before soybean flowering, soil exchangeable K concentrations (0–20 cm depth) in previous corn

---

*Correspondence: Tony J. Vyn, Department of Agronomy, Purdue University, West Lafayette, IN 47907-1150, USA; E-mail: tvyn@purdue.edu.

DOI: 10.1081/PLN-120021049
0190-4167 (Print); 1532-4087 (Online)
www.dekker.com

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

rows were significantly higher than those between corn rows. At the initial flowering stage, trifoliate leaf K concentrations of soybeans in preceding corn rows were 2.0 to 5.3 $\mathrm{g\,kg^{-1}}$ higher than those from corresponding plants between corn rows. Yield of no-till soybeans in previous corn rows increased 10 to 44% compared to those between previous corn rows. Positive impacts of prior corn rows on soil K fertility, soybean leaf K, and soybean yield occurred even when K fertilizer was not applied in the prior corn season. Deep banding of K fertilizer tended to accentuate row vs. between-row effects on soybean leaf K concentrations in low-testing soils. Corn row effects on soybeans were generally not affected by either tillage system or corn hybrid employed in the prior corn crop. Potassium management strategies for narrow-row no-till soybeans should take the potential preceding corn row impacts on soil K distribution into account; adjustments to current soil sampling protocols may be warranted when narrow-row no-till soybeans follow corn on soils with low to medium levels of exchangeable K.

Key Words: Potassium; Soybean; Corn; Row position; No-till; Yield.

INTRODUCTION

Significant vertical stratification of soil exchangeable potassium (K) has frequently been observed in long-term no-till fields.[1–4] This K stratification is characterized by higher soil K concentrations in the surface layer compared to K levels at deeper depth intervals.[5–7] For example, a field survey of soil K stratification on 54 long-term (5–20 yr) no-till fields in Ontario, Canada observed that average soil exchangeable K concentrations in the 0- to 5-cm layer were 158 $\mathrm{mg\,L^{-1}}$, while K levels at the 10- to 20-cm depth were only 92 $\mathrm{mg\,L^{-1}}$.[7] In contrast, soil K distribution is relatively uniform in conventional-till fields to the depth of moldboard plowing.[2,8,9] Lack of soil mixing, surface broadcasting of K fertilizer, high crop residue concentrations at the soil surface, and limited K mobility in soil are all contributing factors to vertical soil K stratification in no-till systems.

Although vertical soil K stratification in no-till generally does not significantly affect the average soil-test K levels for 0- to 15-cm or 0- to 20-cm sampling depths, it results in plant K uptake being more dependent on soil K and root system characteristics in the surface layer. This may reduce plant K uptake, and thus increase the likelihood of K deficiency in crop tissues as well as yield loss in growing seasons when drought occurs, since soil K availability, root growth, and root activity in the surface layer are more vulnerable to drought than those in sub-surface layers. In addition, deposit of crop residue at the soil surface in no-till usually results in higher soil moisture and lower soil temperature in the surface layer, which may reduce soil K availability and restrict root growth early in the season.[10,11] The reduction in plant K uptake and yield by drought or low temperature become severe when soil K concentrations in sub-surface layers are too low to optimize plant K uptake. Because the area of no-till soybeans [*Glycine max* (L.) Merr.] in North America has increased rapidly since the late 1980s, new concerns have been raised about the effectiveness of applying the traditional K fertility management systems originally designed for soybeans in conventional tillage to no-till soybeans. Several recent publications have discussed the influences of K fertilizer placement on K nutrition and yield of no-till soybeans.[12–15]

Long-term no-till management has also resulted in pronounced horizontal heterogeneity of soil exchangeable K.[2,16,17] Horizontal distribution of soil K in no-till fields is affected by the proximity of crop rows, particularly when crop rows are continuously planted in or close to preceding rows.[16,17] Holanda et al.[2] and Mackay et al.[16] observed that in-row and between-row soil K concentrations in approximately the 0- to 25-cm surface layer were similar in conventional tillage (moldboard plow), but that soil K concentrations in rows were greater than those between rows under continuous no-till management. Yibirin et al.[17] reported that soil K concentrations decreased with distance from corn [*Zea mays* L.] rows, in both banded- and broadcast-applied K treatments, at the end of each season in no-till continuous corn. Research in Minnesota[18] demonstrated that soil K levels in crop rows were significantly higher with a deep-banded K treatment, but were almost the same with the zero K control, compared to those between crop rows after a 3-yr corn–soybean rotation study in a ridge tillage system. Higher soil K concentrations in preceding crop rows could be attributed to the release of K from previous crop shoot and root residue to in-row areas, and/or in-row band placement of K fertilizer to the preceding crop. Impacts of previous corn rows and its associated horizontal soil K stratification on K nutrition, growth, and yield of subsequent no-till soybeans are largely unknown.

Since current K fertility management systems for no-till soybeans in corn–soybean rotations do not account for this horizontal soil K stratification caused by preceding corn rows, they may need to be modified to ensure that the horizontal K stratification will not limit K nutrition, growth, and yield of no-till soybeans. The primary objectives of this study were to (1) evaluate the effects of K application rate and placement method in conjunction with tillage systems or corn hybrids used in the corn season on horizontal soil K stratification following corn and (2) investigate the impacts of previous corn rows and any associated horizontal soil K stratification on K nutrition and yield of subsequent no-till soybeans.

MATERIALS AND METHODS

Field experiments involving a corn–soybean rotation were conducted near Paris, Brant County from 1997 to 2000, and near Kirkton, Perth County from 1998 through 1999 in Ontario, Canada. The fields chosen for experiment had been in continuous no-till production for at least 6 yr prior to treatment initiation in the prior corn season. At Paris, the experiments were conducted on adjacent fields in all three years. All fields were tile drained. The growing season received 3347, 3267, and 3033 Ontario Crop Heat Units (OCHU) at Paris in 1998, 1999, and 2000, respectively, and 3036 OCHU at Kirkton in 1999.[19] The soils were classified as a Guelph silt loam (a medium, mixed, alkaline, moderately to very strongly calcareous Typic Hapludalf) at Paris, and a Listowel silt loam (a medium, mixed, weakly to moderately calcareous Typic Hapludalf) at Kirkton. Selected physical and chemical properties of the experimental soils are presented in Table 1.

Paris Tillage Experiment (1998–99)

At Paris, the experiments for the previous corn year were conducted using a randomized complete block split-plot design with four replications in both

Table 1. Selected soil physical and chemical properties of the Ap horizon (0–15 cm) prior to corn planting and planting date for soybeans at Paris and Kirkton from 1998 to 2000.

	Paris			Kirkton
Property (unit)	1998	1999	2000	1999
Texture	Silt loam	Silt loam	Silt loam	Silt loam
Sand ($g\,kg^{-1}$)	375	372	363	103
Silt ($g\,kg^{-1}$)	528	534	531	728
Clay ($g\,kg^{-1}$)	97	94	106	169
pH	5.8	6.4	6.2	6.4
Organic C ($g\,kg^{-1}$)	18	23	20	32
Available K ($mg\,L^{-1}$)[a]	60	47	66	90
Available P ($mg\,kg^{-1}$)[b]	16	13	22	11
Available Mg ($mg\,kg^{-1}$)[c]	182	187	193	143
Planting date (month/day)	05/19	05/17	05/26	05/20

[a] Ammonium acetate extractable K.[20]

[b] Sodium bicarbonate extractable P.[21]

[c] Ammonium acetate extractable Mg.[22]

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

1997 and 1998. Spring tillage systems were randomly assigned to the whole plots, and spring K placement methods were assigned to the split-plots. The following spring tillage systems were used in this study: (1) No-till: Corn was planted using a no-till planter equipped with a single fluted coulter and unit-mounted finger-tined row cleaners; the only soil disturbance was associated with the action of planter-mounted coulters and seed-disk openers. (2) Spring zone-till: Spring tillage was performed in strips approximately 20 cm wide and 17 cm deep on 76-cm centers using a Trans-Till (Row-Tech, Snover, MI). (3) Spring mulch-till: Spring tillage consisted of two passes of a field cultivator to a 10-cm depth just prior to corn planting.

Four placement methods of K fertilizer were used as follows: (1) Deep band: Potash fertilizer was applied in a band 15 cm deep on 76-cm centers, and K fertilization occurred following the completion of spring tillage. Corn was planted directly on the top of K fertilizer bands. (2) Surface broadcast: Potash fertilizer was uniformly broadcast applied to the soil surface just prior to spring tillage. (3) Broadcast plus shallow band: Half of the K fertilizer was applied to the soil surface just prior to spring tillage, and the remainder was banded 5 cm to the side of row and 5 cm below the corn seeding depth at planting. (4) Zero K: No K fertilizer was applied. For all treatments but the latter, potash fertilizer was applied at $100\,\mathrm{kg\,K\,ha^{-1}}$ within 1 d prior to corn planting as muriate of potash (0–0–50). The split-plot was 21 m in length and 3 m in width. The identical experimental design and plot layout as the previous corn season were used for subsequent soybeans in 1998 and 1999, respectively. Detailed information about previous corn management and corn response to K fertility treatments have been reported by Vyn et al.[23]

Paris Hybrid Experiment (2000)

In 1999, the prior corn year for the 2000 soybean investigations, the experiment at Paris was a randomized complete block split-plot design with K placement methods as the whole plots, and corn hybrids as the split-plots. The four K placement methods were exactly the same as those used in 1997 and 1998 in the Paris Tillage experiment described above. The three corn hybrids for which previous corn row effects were monitored were “Pioneer 3820,” “Pioneer 3893,” and “Northrup King Max 357.”

Kirkton Experiment (1999)

At Kirkton, the experimental design was a randomized complete block split-split-plot design with four replicates for the corn year in 1998. Tillage systems were used as the whole plot treatments, fall K application rates were assigned to the split-plots, and spring K rates were used as the split-split-plot treatments. Tillage system in this study included the tillage operations and the corresponding placement method of fall K fertilizer. Two of the three tillage systems present in the corn year were monitored for previous corn row effects in 1999: (1) Zone-till: Soil loosening in strips approximately 20 cm wide by 17 cm deep on 76-cm centers was accomplished in fall using a Trans-Till. The Trans-Till was modified to apply K fertilizer during tillage operations in bands 15 cm deep on the centers of the tilled strips. (2) No-till: Corn was planted no-till; fall K was surface broadcast applied.

Fall K was applied to corn at rates of 0, 42, and 84 kg K ha^{-1} as muriate of potash (0–0–50) using an appropriate method for the tillage system. Spring K was applied at a low rate of 0 kg K ha^{-1}, and high rate of 42 kg K ha^{-1} in the form of muriate of potash (0–0–50) as part of a starter blend. Each split-split-plot was 21 m long and 3 m wide. Detailed information about previous corn management and corn responses to K fertility treatments was presented by Vyn and Janovicek.[24] Only the plots with 0- or 84-kg ha^{-1} rates of fall K, and either spring K rate, were used in the subsequent no-till soybean season.

Soybean Management

Potash fertilizer was not applied after corn or during the soybean season in any site-year. Soybeans were no-till planted in the same direction as the previous corn rows. Efforts were made to plant a maximum number of soybean rows directly over previous corn rows. Soybean row widths were 19 cm for each season at Paris and 38 cm at Kirkton. Soybean variety "Pioneer 9163" was planted in 1998 and 1999, and "NK S08-80" was grown in 2000 at Paris. "Firstline 2801R" soybeans were used at Kirkton in 1999. The planting date for each experiment is presented in Table 1. Soybeans were grown using the recommended no-till management practices for Ontario in each site-year.

Soil Sampling

At Paris, no soil sampling was conducted in 1998 since this study was initiated only after visible leaf K deficiency symptoms were observed in July for soybeans between, but not in, prior corn rows. In 1999, corn row vs. between-row soil sampling was conducted at four depth intervals of 0- to 5-cm, 5- to 10-cm, 10- to 20-cm, and 20- to 30-cm in the zero K treatment on July 5 when soybeans were at V-4 stage. Two soil samples were taken separately, one was randomly collected from soybean rows that were located in previous corn rows, and the other was taken from those that were positioned between former corn rows. Each sample consisted of 10 cores with 2.5-cm diameter. Soil samples were also collected after soybean harvest from the treatments involving deep band, surface broadcast, and zero K using the same protocol as that used at the V-4 stage. In 2000, soil samples were obtained only from the plots previously planted with Pioneer 3820 corn before soybean planting and after soybean harvest utilizing the identical sampling protocol as in 1999. At Kirkton, in-row vs. between-row soil sampling was conducted only after soybean harvest from the no-till plots. Soil samples were air dried, ground, and passed through a 2-mm sieve before analysis.

Soil exchangeable K was extracted using 1 M ($pH = 7.0$) ammonium acetate solution,[20] and determined by atomic absorption spectroscopy. In this study, Ontario soil-test K interpretations for samples at the 0- to 15-cm depth are used. Boundaries of soil exchangeable K in low, medium, high, very high, and excessive categories are <61, 61–120, 121–150, 151–250, and $>250\,\mathrm{mg\,L^{-1}}$ (milligrams of K per liter of soil) for soybeans, respectively.[25] Soybean yield response to K fertilization is expected on soils with low to medium K levels.

Soybean Measurement

Two soybean leaf samples, each consisting of 20 most recently fully developed trifoliate leaves (petiole included) of soybeans were randomly collected at initial flowering stage (R1) in mid-to-late July (July 22 in 1998, July 19 in 1999, and July 20 in 2000 at Paris, and July 16 in 1999 at Kirkton) from each plot in each site-year for the determination of tissue K concentrations. One sample was taken from soybeans positioned in previous corn rows; the other was collected from those located between previous corn rows. In addition, leaf samples were also taken at V-4 stage from the zero K treatment at Paris on July 5 1999; the sampling protocol was the same as that used at the initial flowering stage. Leaf samples were dried in a forced-air oven at 65°C for at least 3 d, and ground to pass a 1-mm screen. Leaf samples were analyzed for K after ashing the samples at 485°C and dissolving the residues in 1 M HCl. Potassium in the plant digests was determined by atomic absorption spectroscopy.

After soybeans had matured, 8-m lengths of soybean rows both in and between the previous corn rows were hand harvested separately from the zero K treatment in no-till at Paris in 1998, from deep band, surface broadcast, and the zero K treatment in all three tillage systems at Paris in 1999, and from all treatments outlined above at Paris in 2000 and at Kirkton in 1999. Seed samples were taken at harvest for the determinations of moisture and K contents. Grain yield was adjusted to a moisture content of 130 g kg^{-1}. Seed K concentrations were determined using the same procedures as those for leaf samples. Daily rainfall and air temperature were measured, or obtained from the nearest weather station for each site-year (data not presented).

Statistical Analysis

At Paris, seed yield data in 1998 were analyzed using a paired-*t* test. The data of soil exchangeable K and leaf K concentrations from the zero K treatment at V-4 stage in 1999 were analyzed using an analysis of variance appropriate for a randomized complete block split-plot design; spring tillage systems were assigned to the whole plots and soybean row positions relative to previous corn rows were assigned to the split-plots. The results of leaf K at initial flowering stage in both 1998 and 1999, and seed yield and soil K concentrations at harvest in 1999 were analyzed using a split-split-plot model assigning tillage systems to the whole plots, K placement methods to the split-plots, and soybean row positions to the split-split-plots. In 2000, soil K levels before soybean planting and after soybean harvest were analyzed using a split-plot design model with K placement methods as the whole plots and soybean row positions as the split-plots; leaf K concentrations, seed yield, and seed K concentrations were analyzed using a split-split-plot model assigning K placement methods to the whole plots, corn hybrids to the split-plots, and soybean row positions to the split-split-plots. At Kirkton, soil K levels after soybean harvest were analyzed using a split-split-plot design with fall K rates as the whole plots, spring K as the split-plots, and soybean row positions as the split-split-plots; all other data were analyzed using a split-split-split-plot design with tillage systems as the whole plots, fall K rates as the split-plots, spring K as the split-split-plots, and soybean row positions as the split-split-split-plots. Mean separations of all variables were accomplished using Fisher's protected LSD at $P = 0.05$. Only data for subsequent no-till soybeans are reported.

RESULTS AND DISCUSSION

Weather conditions during the 3 yr of this study varied considerably at Paris (data not presented). The 1998 experiment received well below normal rainfall throughout the growing season, particularly in April, May, and September; the total rainfall from April to October was only 375 mm, far below the 30-yr average of 579 cm. Rainfall in 1999 was adequate and uniformly distributed. The 2000 growing season had a total rainfall of 710 mm from April to October, significantly higher than the 30-yr average; both May and June received at least double the normal rainfall. At Kirkton, rainfall in 1999 was adequate and evenly distributed throughout the growing season (data not presented).

Soil Exchangeable Potassium Before Soybean Flowering

At Paris, soil testing on July 5, 1999 showed that soil exchangeable K concentrations at the 0- to 5-cm, 5- to 10-cm, 10- to 20-cm, and 20- to 30-cm depth intervals in previous corn rows were 28, 11, 7, and 4 mg L^{-1} higher than those between previous corn rows, respectively, in the zero K treatment averaged over three tillage systems at V-4 stage (Fig. 1), suggesting more available soil K was present in previous corn rows even when K fertilizer was not applied to previous corn. Neither spring tillage system nor K placement before corn significantly affected the previous corn row effects on soil K (data not presented).

At Paris in 2000, horizontal soil K distribution in the top 20-cm layer before soybean planting was also significantly affected by previous corn rows (Fig. 2). Moreover, K placement did not affect corn row effects on soil K distribution before soybean planting (data not presented). Averaged over four K treatments from the previous corn year, soil K concentrations in prior corn rows were 48 mg L^{-1} higher in 0- to 5-cm, 29 mg L^{-1} higher in 5- to 10-cm, and 7 mg L^{-1} higher in 10- to 20-cm, than those between corn rows. The results of this study were consistent with those of Yibirin et al.[17] who observed that K placement method did not influence the differences in soil K between row and

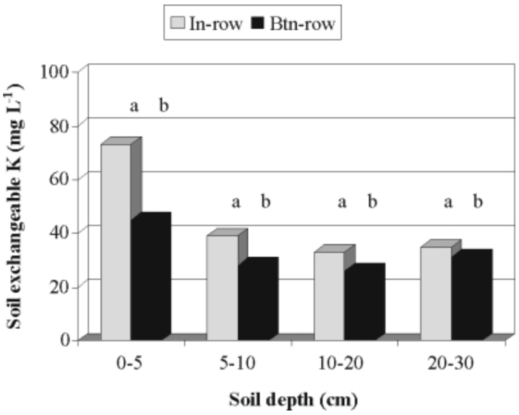

Figure 1. Previous corn row effects on soil exchangeable K concentrations in the zero K treatment at soybean V-4 stage averaged over the three prior tillage systems at Paris in 1999. In-row, in previous corn rows; btn, between previous corn rows. Within each soil depth interval, bars labeled with the same letter are not significantly different at $P = 0.05$ according to Fisher's protected LSD test.

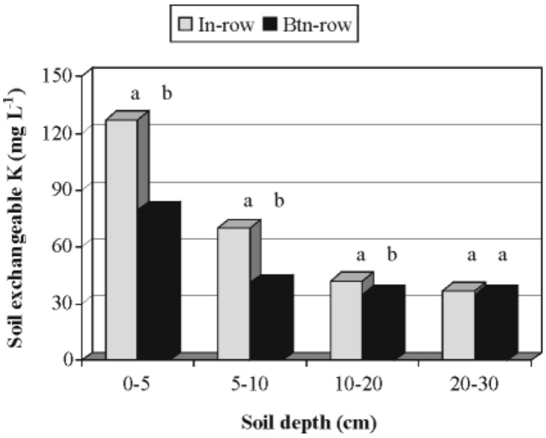

Figure 2. Previous corn row effects on soil exchangeable K concentrations before soybean planting averaged over the four prior K placement treatments at Paris in 2000. In-row, in previous corn rows; btn, between previous corn rows. Within each soil depth interval, bars labeled with the same letter are not significantly different at $P = 0.05$ according to Fisher's protected LSD test.

inter-row zones. This horizontal soil K stratification caused by previous corn rows may affect plant K nutrition of subsequent no-till soybeans.

Mid-season Soybean Potassium Nutrition

Visual K deficiency symptoms of soybeans were evident in July and August for both 1998 and 1999 at Paris in plots where K had not been applied in the previous corn year. These symptoms were more prevalent in plants positioned between previous corn rows. Leaf K concentrations for soybeans in previous corn rows were more than double those between corn rows in the zero K treatment at V-4 stage at Paris in 1999 (data not presented). This coincided with higher soil exchangeable K levels in prior corn rows at this stage (Fig. 1).

Leaf K concentrations of soybeans at initial flowering stage in preceding corn rows were significantly higher than those between corn rows averaged over 1998 and 1999 at Paris (Table 2). Potassium placement significantly affected the preceding corn row effects on leaf K. Deep banding and broadcast plus shallow banding resulted in greater differences in leaf K of soybeans in previous corn rows, vs. those between previous corn rows, compared to zero K and surface broadcast. However, prior corn row effects on leaf K concentra-

Table 2. Previous corn row effects on leaf K concentrations at initial flowering stage at Paris from 1998 to 2000.[a]

	Year and soybean row position			
	1998–99 average		2000	
Treatment in prior corn year	In[b]	Btn	In	Btn
	Leaf K, g kg^{-1}			
K placement				
Deep band	19.1a[c]	13.8b	28.1	23.1
Surface broadcast	18.7a	15.2b	26.6	24.0
Broadcast + shallow band	19.0a	13.7b	28.0	24.6
Zero K	15.2a	11.7b	25.9	22.8
Average	18.0a	13.6b	27.2a	23.6b
Treatment effects				
Corn row (C)	***		***	
Tillage (T) × C	ns		NA[d]	
K Placement (P) × C	*		ns	
T × P × C	ns		NA	
Hybrid (H) × C	NA		ns	
H × P × C	NA		ns	

Note: ns, not significant at the 0.05 probability level; * and ***, significant at the 0.05 and 0.001 probability levels, respectively.

[a] Leaf K results are averaged over the three prior tillage systems for 1998–99 average, and averaged over the three previous corn hybrids in 2000.

[b] In, in previous corn rows; Btn, between previous corn rows.

[c] Means in a row within 1998–99 average or 2000 followed by the same letter are not significantly different at $P = 0.05$ according to Fisher's protected LSD test.

[d] Not applicable.

tions were always statistically significant no matter what K treatments were employed for the previous corn. Previous corn row effects on leaf K nutrition of subsequent narrow-row no-till soybeans also occurred even when K fertilizer had not been applied to preceding corn; this may be a result of the elevated soil K levels associated with K release from the corn stover and roots in the corn row areas. Spring tillage system did not affect leaf K responses to prior corn rows. In 2000, corn row effects on leaf K concentrations were not influenced by K placement (Table 2) or corn hybrid treatments (data not presented) in prior corn. Leaf K concentrations of soybeans positioned in previous corn rows averaged 3.6 g kg^{-1} higher than those between corn rows (Table 2).

At Kirkton, differences in leaf K concentrations of soybeans in previous corn rows vs. between corn rows were not significantly influenced by fall-applied K or tillage system, but were affected by spring-applied K imposed on previous corn (Table 3). Averaged over fall K and tillage treatments, leaf K concentrations of soybeans in preceding corn rows were 3.1 g kg^{-1} higher than those between corn rows in the treatments where corn received no spring-applied K. However, in-row vs. between-row differences in leaf K were negligible when K fertilizer was applied in a starter band at corn seeding. In the latter case, spring-banded K increased overall leaf K concentrations between rows proportionately more than those in prior corn rows; this suggests that some of the residual starter-banded K was available to soybeans planted between rows.

Table 3. Previous corn row effects on leaf K concentrations and seed yield at Kirkton in 1999.[a]

	Leaf K, g kg^{-1}		Yield, Mg ha^{-1}	
Treatment in prior corn year	In[b]	Btn	In	Btn
Fall K (kg ha^{-1})				
0	19.1	17.3	3.76	3.30
84	22.8	20.5	3.71	3.52
Spring K (kg ha^{-1})				
0	20.5a[c]	17.4b	3.71	3.31
42	21.3a	20.4a	3.76	3.51
Average	20.9a	18.9b	3.74a	3.41b
Treatment effects				
Corn row (C)	***		**	
Tillage (T) × C	ns		ns	
Fall K (F) × C	ns		ns	
T × F × C	ns		ns	
Spring K (S) × C	*		ns	
T × S × C	ns		ns	
F × S × C	ns		ns	
T × F × S × C	ns		ns	

Note: ns, not significant at the 0.05 probability level; *, **, and ***, significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

[a] Values are averaged over the three prior tillage systems.

[b] In, in previous corn rows; Btn, between previous corn rows.

[c] Means in a row within leaf K or yield followed by the same letter are not significantly different at $P = 0.05$ according to Fisher's protected LSD test.

Soybean Yield

At Paris, seed yield of soybeans in previous corn rows was 44% (0.96 Mg ha^{-1}) higher than those between previous corn rows with the zero K treatment in no-till in 1998 (Table 4). In 1999, yield increases for soybeans in previous corn rows, vs. between rows, averaged 10% (0.31 Mg ha^{-1}) over the three K treatments and three tillage systems. However, soybean yield was not significantly higher in previous corn rows in 2000 (Table 4), even though leaf K concentrations of soybeans in previous corn rows were greater than those

Table 4. Previous corn row effects on seed yield at Paris from 1998 to 2000.[a]

Treatment in prior corn year	Year and soybean row position					
	1998		1999		2000	
	In[b]	Btn	In	Btn	In	Btn
	Yield, Mg ha^{-1}					
K placement						
Deep band	ND[c]	ND	3.14	2.90	3.77	3.91
Surface broadcast	ND	ND	3.41	3.14	3.73	4.00
Broadcast + shallow band	ND	ND	ND	ND	3.89	3.45
Zero K	2.36a[d]	1.40b	3.49	3.04	3.69	3.68
Average	ND	ND	3.34a	3.03b	3.77	3.76
Treatment effects						
Corn row (C)	*		*		ns	
Tillage (T) × C	ND		ns		NA[e]	
K placement (P) × C	ND		ns		ns	
T × P × C	ND		ns		NA	
Hybrid (H) × C	NA		NA		ns	
H × P × C	NA		NA		ns	

Note: ns, not significant at the 0.05 probability level; *, significant at the 0.05 probability level.

[a] Values are for no-till alone in 1998, but averaged over the three prior tillage systems in 1999, and averaged over three previous corn hybrids in 2000.

[b] In, in previous corn rows; Btn, between previous corn rows.

[c] Not determined.

[d] Means in a row within each year followed by the same letter are not significantly different at $P = 0.05$ according to Fisher's protected LSD test.

[e] Not applicable.

between prior corn rows. This may be because leaf K levels in the mid-season were very high ($>22\,\mathrm{g\,kg^{-1}}$) for soybeans positioned in both areas, which suggests that K nutrition was unlikely to have been a limiting factor for soybean yields in 2000. The rainfall in June 2000 was 218 mm, 2.3 times higher than the 30-yr average of 87 mm. Higher soil moisture during critical periods in the growing season could greatly increase soil K availability and plant K uptake, and thus decrease soybean responses to K fertilizer applications.[26]

At Kirkton, the yield increases associated with soybeans positioned in previous corn rows averaged 9.7% ($0.33\,\mathrm{Mg\,ha^{-1}}$) relative to those between previous corn rows (Table 3). Neither fall K, spring K, nor tillage system treatments for previous corn influenced the preceding corn row effects on soybean yield.

In our previous investigations on the residual effects of K placement for corn on subsequent no-till soybeans,[27] soybean yield increases associated with combined fall K and spring K fertilizer in prior corn never exceeded 8%, relative to that after zero K fertilizer in corn. Low yield soybean responses to residual K fertilizer may be due, in part, to the row spacing used in those experiments (38 cm) and the low proportion of subsequent no-till soybean rows positioned in proximity to prior corn rows. Since a bulk-harvest (i.e., plot combine) approach was used, the yield results above were actually the averages of soybean rows from both in and between previous corn rows. If previous corn row effects on soybean yield are evident, maximum residual effects from K fertilizer will be apparent when soybean rows are all grown in proximity to previous corn rows.

Soil Potassium Fertility After Soybean Harvest

Differences in soil exchangeable K concentrations for in-row vs. between-row positions persisted even after soybean harvest at Paris in both 1999 (Table 5) and 2000 (data not presented). In 1999, soil K levels in previous corn rows averaged $20\,\mathrm{mg\,L^{-1}}$ higher, relative to those between corn rows in the 0- to 5-cm layer (Table 5). At the 5- to 10-cm depth, soil K concentrations in previous corn rows increased $24\,\mathrm{mg\,L^{-1}}$ with deep band and $15\,\mathrm{mg\,L^{-1}}$ with broadcast compared to those between prior corn rows. In the 10- to 20-cm layer, deep banded vs. broadcast trends were similar to those at the 5- to 10-cm depth. No such differences in the 5- to 10-cm or 10- to 20-cm layers were observed with the zero K treatment. Previous corn row effects on soil K concentrations after soybean harvest were unaffected by spring tillage system used for the prior corn crop (data not presented).

At Paris in 2000, however, soil K differences associated within and between previous corn rows were not significantly influenced by K placement at any of the four depth intervals (data not presented). Average soil K levels in prior corn rows were 13 mg L^{-1} higher in the 0- to 5-cm layer and 12 mg L^{-1} greater at the 5- to 10-cm depth than those between corn rows; however, previous corn row effects were not significant in either 10- to 20-cm or 20- to 30-cm layers. In addition, overall soil K concentrations were much lower in fall than they were in spring as expected; row vs. between row differences were less pronounced in fall.

At Kirkton, soil K concentrations in previous corn rows differed significantly from those between prior corn rows at all four depth intervals, and the effects of preceding corn rows on soil K were affected by fall K application in the 5- to 10-cm, 10- to 20-cm, and 20- to 30-cm layers (Table 6). Increases in soil K levels associated with previous corn rows averaged 20 mg L^{-1} in the 0- to 5-cm layer. Concentration gains associated with row areas ranged from 45 mg L^{-1} at the 10- to 20-cm depth to 17 mg L^{-1} at the 20- to 30-cm depth

Table 5. Previous corn row effects on soil exchangeable K concentrations after soybean harvest at Paris in 1999.[a]

Treatment in prior corn year	Soil depth (cm) and soybean row position							
	0–5		5–10		10–20		20–30	
	In[b]	Btn	In	Btn	In	Btn	In	Btn
	Soil K, mg L^{-1}							
K placement								
Deep band	88	67	52a[c]	28b	37a	28b	40	35
Surface broadcast	80	54	43a	28b	31a	26b	31	29
Zero K	58	43	29a	25a	25a	24a	38	29
Average	75a	55b	42a	27b	31a	26b	37	31
Treatment effects								
Corn row (C)	**		***		***		ns	
Tillage (T) × C	ns		ns		ns		ns	
K placement (P) × C	ns		**		*		ns	
T × P × C	ns		ns		ns		ns	

Note: ns, not significant at the 0.05 probability level; *, **, and ***, significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

[a] Values are averaged over the three prior tillage systems.

[b] In, in previous corn rows; Btn, between previous corn rows.

[c] Means in a row within each soil depth interval followed by the same letter are not significantly different at $P = 0.05$ according to Fisher's protected LSD test.

Table 6. Previous corn row effects on soil exchangeable K concentrations after soybean harvest at Kirkton in 1999.[a]

Treatment in prior corn year	Soil depth (cm) and soybean row position							
	0–5		5–10		10–20		20–30	
	In[b]	Btn	In	Btn	In	Btn	In	Btn
	Soil K, mg L^{-1}							
Fall K (kg ha^{-1})								
0	95	78	62a[c]	56a	50a	50a	56a	55a
84	108	83	80a	55b	95a	50b	72a	55b
Spring K (kg ha^{-1})								
0	91	75	66	53	72	48	65	55
42	111	86	76	58	73	53	63	56
Average	101a	81b	71a	55b	72a	50b	64a	55a
Treatment effects								
Corn row (C)	***		***		***		**	
Fall K (F) × C	ns		**		***		**	
Spring K (S) × C	ns		ns		ns		ns	
F × S × C	ns		ns		ns		ns	

Note: ns, not significant at the 0.05 probability level; ** and ***, significant at the 0.01 and 0.001 probability levels, respectively.

[a] Values are for no-till alone.

[b] In, in previous corn rows; Btn, between previous corn rows.

[c] Means in a row within each soil depth interval followed by the same letter are not significantly different at $P = 0.05$ according to Fisher's protected LSD test.

interval when 84 kg ha^{-1} of K fertilizer was applied in fall to previous corn. However, no significant differences associated with prior corn rows were observed in the treatments not receiving fall-applied K in 5- to 10-cm, 10- to 20-cm or 20- to 30-cm layers.

Soil K results at both Paris and Kirkton indicate that soil K concentrations in prior corn rows were still significantly higher to a depth of at least 10 cm in the K-fertilized treatments and 5 cm in the zero K treatment even after the soybean harvest. These differences may affect the no-till crop following soybeans, especially on low to medium K soils. The soil K results of this study were consistent with Holanda et al.[2] However, Rehm[18] observed that soil K concentrations were distributed rather uniformly between rows in a continuous ridge tillage system when K fertilizer was not applied, whereas higher soil K levels were observed in row areas when 148 kg ha^{-1} K fertilizer was deep-banded in ridge centers each fall.

Based on the results of this study, the extent of soybean responses to direct or residual K application in a corn–soybean rotation may depend on the relative proximity of soybean rows to previous corn rows. If subsequent no-till soybeans are all planted over previous corn rows, soybean response to direct K fertilization will be minimized, but soybean response to residual K application will be maximized. Soybean responses to residual K application may even be greater in soybean rows where K fertilizer was banded prior to or at planting of corn, rather than surface broadcast applied. Although there are a few reports of pronounced horizontal stratification of soil exchangeable K associated with prior corn rows,[16,17] this is the first report studying the effects of previous corn rows on plant K nutrition and yield of subsequent no-till soybeans.

Differences in soil exchangeable K levels before soybean flowering, leaf K concentrations at flowering, and yield of subsequent no-till soybeans associated with previous corn rows suggest that the current soil sampling scheme using a composite sample, randomly collected from a specified area, has not only significantly underestimated soil K levels in the previous corn row areas, but also overestimated K concentrations between prior corn row zones. Correspondingly, resulting K fertilizer recommendations would have been higher than actually required by subsequent no-till soybeans in the previous corn row areas, but lower than the actual requirement for soybeans positioned between corn row areas. Therefore, there may be a need to take soil samples from areas in previous corn rows and between corn rows separately, and then make separate K fertilizer recommendations correspondingly. However, this would double the costs of soil sampling and, if row effects are significant, complicate the application of K fertilizer at varying rates in such narrow zones. Alternatively, a simple and conservative way is to take a composite soil sample only from between previous corn row areas, and use the result of this sample to make K fertilizer recommendations for the entire field. Although this may significantly underestimate soil K fertility levels in previous corn rows, and result in over-application of K fertilizer for subsequent no-till soybeans in previous corn rows; this may still be a preferable strategy due to relatively low cost of K fertilizers, low toxicity of luxurious K uptake to plants, and high cost of yield loss if insufficient soil exchangeable K is available to soybeans.

Although this study was limited to corn row effects on K status, other soil nutrients such as P may also be horizontally stratified (i.e., higher concentrations in preceding corn rows). Furthermore, some physical, chemical, and biological properties of soil (such as soil mechanical impedance, moisture, pH, and microbial communities) may also be significantly affected by previous corn rows. We acknowledge that some of these additional factors may also have contributed to enhanced soybean yield in prior corn row areas in this study.

CONCLUSIONS

Previous corn rows resulted in substantial impacts on soil K fertility, plant K nutrition, and seed yield of subsequent narrow-row, no-till soybeans. Soil exchangeable K concentrations in preceding corn rows exceeded those between previous corn rows at depths up to 20 cm regardless of K application rate and K placement method for prior corn. Leaf K concentrations of subsequent no-till soybeans in prior corn rows were 2.0–5.3 g kg^{-1} higher than those between corn rows. Yield of no-till soybeans in previous corn rows increased 10 to 44% compared to those between previous corn rows. Previous corn row effects on soil K fertility, K nutrition, and yield of no-till soybeans occurred even when K fertilizer was not applied in the prior corn season. Deep banding of K fertilizer tended to accentuate row vs. between-row effects on leaf K concentrations on low-testing soils. Corn row effects were generally not influenced by either tillage system or corn hybrid employed in the previous corn season.

Our results suggest that the proportion of soybean rows planted in proximity to previous corn rows will thus affect yield benefits associated with preceding corn rows, particularly on low to medium K soils. In addition, the most efficient K management strategies for narrow-row no-till soybeans should consider the potential impacts of previous corn rows on horizontal soil K distribution. Adjustments to the current soil sampling protocols for soil K may be warranted when narrow-row no-till soybeans follow corn on low to medium K soils. Horizontal soil K stratification persisted even after soybean harvest; these differences may affect the no-till crop following soybeans on low K soils.

ACKNOWLEDGMENTS

Research was supported by Purdue Research Foundation, Ontario Soybean Growers' Marketing Board, Agricultural Adaptation Council of Canada, and Ontario Ministry of Agriculture, Food, and Rural Affairs.

REFERENCES

1. Crozier, C.R.; Naderman, G.C.; Tucker, M.R.; Sugg, R.E. Nutrient and pH stratification with conventional and no-till management. Commun. Soil Sci. Plant Anal. **1999**, *30*, 65–74.
2. Holanda, F.S.R.; Mengel, D.B.; Paula, M.B.; Carvado, J.G.; Bertoni, J.C. Influence of crop rotations and tillage systems on phosphorus and potassium stratification and root distribution in soil profile. Commun. Soil Sci. Plant Anal. **1998**, *29*, 2383–2394.
3. Karathanasis, A.D.; Wells, K.L. A comparison of mineral weathering trends between two management systems on a catena of Loess-derived soils. Soil Sci. Soc. Am. J. **1989**, *53*, 582–588.
4. Sprague, A.D.; Triplett, G.B. *No-Tillage and Surface Tillage Agriculture: The Tillage Revolution*; John Wiley & Sons: New York, 1986.
5. Ketcheson, J.W. Effect of tillage on fertilizer requirements for corn on a silt loam soil. Agron. J. **1980**, *72*, 540–542.
6. Robbins, S.G.; Voss, R.D. Phosphorus and potassium stratification in conservation tillage systems. J. Soil Water Cons. **1991**, *46*, 298–300.
7. Yin, X.H.; Vyn, T.J. Potassium and phosphorus stratification in long-term no-till fields in Ontario. In *Soil Science Divisions Annual Meeting Abstracts*, Salt Lake City, Utah, October 31–November 4, 1999; American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America: Madison, WI, 1999; 282 pp.
8. Cruse, R.M.; Yakle, G.A.; Colvin, T.C.; Timmons, D.R.; Mussleman, A.L. Tillage effects on corn and soybean production in farmer-managed, university-monitored field plots. J. Soil Water Cons. **1983**, *38*, 512–514.
9. Fink, R.J.; Wesley, D. Corn yields as affected by fertilization and tillage system. Agron. J. **1974**, *66*, 70–71.
10. Barber, S.A. Effect of tillage practice on corn (*Zea mays* L.) root distribution and root morphology. Agron. J. **1971**, *63*, 724–726.
11. Fortin, M.C. Soil temperature, woil water, and no-till corn development following in-row residue removal. Agron. J. **1993**, *85*, 571–576.
12. Borges, R.; Mallarino, A.P. Grain yield, early growth, and nutrient uptake of no-till soybean as affected by phosphorus and potassium placement. Agron. J. **2000**, *92*, 380–388.

13. Buah, S.S.J.; Polito, T.A.; Killorn, R. No-tillage soybean response to banded and broadcast and direct and residual fertilizer phosphorus and potassium applications. Agron. J. **2000**, *92*, 657–662.
14. Yin, X.H.; Vyn, T.J. Soybean responses to potassium placement and tillage alternatives following no-till. Agron. J. **2002**, *94*, 1367–1374.
15. Yin, X.H.; Vyn, T.J. Potassium placement effects on yield and seed composition of no-till soybean seeded in alternate row widths. Agron. J. **2003**, *95*, 126–132.
16. Mackay, A.D.; Kladivko, E.J.; Barber, S.A.; Griffith, D.R. Phosphorus and potassium uptake by corn in conservation tillage systems. Soil Sci. Soc. Am. J. **1987**, *51*, 970–974.
17. Yibirin, H.; Johnson, J.W; Eckert, T.D. No-till corn production as affected by mulch, potassium placement, and soil exchangeable potassium. Agron. J. **1993**, *85*, 639–644.
18. Rehm, G.W. Impact of banded potassium for corn and soybean production in a ridge-till planting system. Commun. Soil Sci. Plant Anal. **1995**, *26*, 2725–2738.
19. Brown, D.M.; Bootsma, A. *Crop Heat Units for Corn and other Warm-Season Crops in Ontario*; Ontario Ministry of Agriculture and Food: Ontario, Canada, 1993; Factsheet AGDEX 111/31.
20. Bates, T.E.; Richards, J.E. Available potassium. In *Soil Sampling and Methods of Analysis*; Carter, M.R., Ed.; Lewis Publishers: Boca Raton, FL, 1993; 59–64.
21. Schoenau, J.J.; Karamamos, R.E. Sodium bicarbonate-extractable P, K, and N. In *Soil Sampling and Methods of Analysis*; Carter, M.R., Ed.; Lewis Publishers: Boca Raton, FL, 1993; 51–58.
22. Simard, R.R. Ammonium acetate-extractable elements. In *Soil Sampling and Methods of Analysis*; Carter, M.R., Ed.; Lewis Publishers: Boca Raton, FL, 1993; 39–42.
23. Vyn, T.J.; Galic, D.M.; Janovicek, K.J. Corn response to potassium placement in conservation tillage. Soil Till. Res. **2002**, *67*, 159–169.
24. Vyn, T.J.; Janovicek, K.J. Potassium placement and tillage system effects on corn response following long-term no-till. Agron. J. **2001**, *93*, 487–495.
25. OMFARA. *Chapter 5: Soybeans. Field Crop Recommendations 1997–1998*; Ontario Ministry of Agriculture, Food, and Rural Affairs: Ontario, Canada, 1997; Publ. 296, 67–74.
26. Johnson, J.W.; Wallingford, W. Weather-stress yield loss. Crops Soils Mag. **1983**, *35*, 15–18.
27. Yin, X.H.; Vyn, T.J. Residual Effects of Potassium Placement and Tillage Systems for Corn on subsequent no-till soybean. Agron. J. **2002**, *94*, 1112–1119.