The Effects of Fertilizer, Environment and Location on Cadmium Accumulation in Flax

Cynthia A. Grant[1] and Guy P. Lafond[2]
Agriculture and Agri-Food Canada, Brandon Research Centre [Project #8453]
[1]Box 1000A, R.R. #3, Brandon, MB, R7A 5Y3
[2]Indian Head Research Farm, Box 760, Indian Head, SK, S0G 2K0

EXECUTIVE SUMMARY

Field studies were conducted at a range of sites in Saskatchewan and Manitoba over a three-year period to determine the effect of year to year variability, location and applications of N, P, K, S and Zn on cadmium concentration in flaxseed.

Location had the greatest impact on cadmium concentration, with concentrations ranging by more 5-fold from site to site. Year to year variability was also substantial. Fertilizer applications influenced cadmium concentration in flax at some locations, although effects were relatively small compared to that of location. Where fertilizer effects occurred, application of N generally led to lower Cd concentration, although increases sometimes occurred. Nitrogen may reduce Cd concentration through dilution when Cd concentration in the medium is low and crop production increases with N application. In contrast, N may sometimes mobilize Cd through osmotic effects or microsite acidification, leading to increases in Cd concentration. This appeared to happen more frequently when N was applied in combination with other nutrients. Placement of N had little effect on Cd concentration. Use of ammonium sulphate sometimes led to higher concentrations of Cd than did other N sources. The greater acidifying effect of ammonium sulphate could have enhanced Cd availability.

Phosphate fertilizer contains Cd at varying levels, depending on its source. Therefore, in the long term, application of Cd could increase Cd content of the soil and encourage higher Cd concentration in crops. However, the short-term effect of P was small in these trials. Where P had an influence on Cd concentration, it generally led to higher levels. However, the effect was inconsistent.

In other studies, Zn has been shown to reduce Cd concentration of crops. However, in this study, only "sausage" application of Zn SO_4 decreased Cd concentration, while application of EDTA-chelated Zn increased Cd concentration of flaxseed. Sulphur did not generally influence Cd concentration. Potassium chloride tended to increase Cd concentration in flaxseed and the effect was somewhat more consistent than the effects of the other fertilizer materials tested. Chloride can form complexes with Cd in the soil, increasing its mobility and enhancing its availability for crop uptake.

Based on the results of these studies, it appears that site selection is the most important management factor that can be used to reduce Cd concentration in flax. Flax that is intended for entry into the food market, where low Cd level is desired, should be produced on soils that have been shown to produce low-Cd crops. Application of N to optimize crop yield should not lead to higher Cd levels. Application of P or KCl could lead to higher Cd levels, but the effect is small relative to the impact of location. In an area marginal for production of low-Cd flax, over-fertilization or use of "just-in-case" applications of these nutrients should be avoided. In some

studies, Zn has been shown to decrease Cd in flax, but only a "sausage" application of $ZnSO_4$ was effective at the single location in this study. However there was no yield response to Zn application at this location, so it is possible that Zn application may reduce Cd concentration on locations where Zn level in the soil is marginal or deficient.

Objectives: Determine the effects of fertilizer, soil type and location on cadmium accumulation in flax seed. Correlate the uptake of cadmium with weather variables and soil background levels of cadmium.

Field Study 1: Nitrogen and Phosphorus Management
Experiments were conducted at four locations from 1996 to 1998 to evaluate the impact of N and P source and placement on the yield and P accumulation in flax and on seed quality. Seed samples were collected at final harvest and analysed for cadmium content

Table 1: Impact of Treatment and Location on Cadmium Concentration in the Seed (1996)

trt	N - Forms	N - Placement	P - Placement	Melfort	Minnedosa	Morden	Indian Head
				---------------------------ppb-------------------------			
1	Urea	Spring Band	Side-Band	193	203	1218	622
2	Urea	Spring Band	Seed-Placed	186	205	1237	679
3	Amm Sulf	Spring Band	Side-Band	239	231	1247	728
4	Urea	Side-Band	Side-Band	229	206	1285	702
5	Amm Nitr	Side-Band	Side-Band	210	210	1220	669
6	Amm Sulf	Side-Band	Side-Band	218	226	1311	727
7	Urea+NBPT	Side-Band	Side-Band	221	228	1322	664
8	Urea	Spring Band	Spring Band	208	230	1294	631
9	Urea	Spring-Band (3-4" spread)	Spring Band	177	209	1178	.
10	Urea	Spring Band	Control-No P	185	191	1289	582

Effect of Location
Seed Cd level varied tremendously with location (Tables 1 to 6). Levels of Cd in flax were highest at the Morden location. Morden is located in an area where soils are derived from black shale that tends to increase Cd concentration in plants. A 300 ppm level has been used as a limit for import into some European countries. Levels of Cd in the seed at Melfort were below 300 ppm in all three years of the study, while in Minnedosa levels were below 300 ppm in all treatments in 1996, above 300 ppm in all treatments in 1997 and below 300 ppm in most treatments in 1998. Cadmium concentration in flaxseed grown at Indian Head was intermediate, being 2 to 3 times the levels at Melfort and Minnedosa, but slightly more than half of the concentration of the flaxseed from Morden. The ranking of Cd concentrations from location to location remained constant from year to year, although there was yearly variation in the Cd concentration at each location. The year to year variation is caused by environmental factors. Other research has indicated that Cd concentration in flax may increase with increasing available moisture during the growing season.

Table 2: Probability levels for the effect of N and P treatment and location on cadmium concentration of flax seed (1996)

Source	Melfort	Minnedosa	Morden	Indian Head
Treat	0.0003	ns	ns	ns
CV	11.44	18.90	8.48	20.48
Contrast				
Control vs rest	0.0218	ns	ns	ns
1 vs 2	ns	ns	ns	ns
1 vs 4	0.0116	ns	ns	ns
4 vs 7	ns	ns	ns	ns
4 vs 8	ns	ns	ns	ns
1 + 4 vs 3 + 6	0.0821	ns	ns	ns
4 vs 5	ns	ns	ns	ns
8 vs 9	0.0301	ns	0.0601	ns
5 vs 7	ns	ns	ns	ns

Effect of Fertilizer Management

Application of fertilizer phosphorus tended to increase the Cd concentration of flaxseed at Melfort in 1996 and 1997 and at Morden in 1998. There was no significant effect of fertilizer management at Minnedosa in 1996 or Indian Head in 1996 or 1998.

Source of N fertilizer impacted on Cd content in flax. At Melfort in 1996 and at Minnedosa and Indian Head in 1997, Cd concentration was higher when ammonium sulphate was used as the N source as compared to urea. At Indian Head in 1997, Cd concentration also tended to be higher when ammonium nitrate was used rather than urea. Ammonium sulphate tends to be a more acidifying source of N than urea, which may increase the solubility and phytoavailability of soil reserves of Cd.

Table 3: Impact of Treatment and Location on Cadmium Concentration in the Seed (1997)

trt	N - Forms	N - Placement	P - Placement	Melfort	Minnedosa	Morden	Indian Head
				ppb			
1	Urea	Spring Band	Side-Band	168	361	1365	825
2	Urea	Spring Band	Seed-Placed	183	349	1459	922
3	Amm Sulf	Spring Band	Side-Band	166	375	1375	1060
4	Urea	Side-Band	Side-Band	181	330	1438	950
5	Amm Nitr	Side-Band	Side-Band	175	360	1452	1104
6	Amm Sulf	Side-Band	Side-Band	203	447	1419	960
7	Urea+NBPT	Side-Band	Side-Band	171	350	1419	951
8	Urea	Spring Band	Spring Band	174	317	1478	910
9	Urea	Spring-Band (3-4" spread)	Spring Band	157	326	1479	.
10	Urea	Spring Band	Control-No P	154	341	1428	871

Table 4: Effect of N and P treatment and location on cadmium concentration of flax seed (1997)

Source	Melfort	Minnedosa	Morden	Indian Head
Treat	0.0978	0.0053	ns	0.0401
CV	14.87	14.28	7.4	14.77
Contrast				
Control vs rest	0.0557	ns	ns	ns
1 vs 2	ns	ns	ns	ns
1 vs 4	ns	ns	ns	ns
4 vs 7	ns	ns	ns	ns
4 vs 8	ns	ns	ns	ns
1 + 4 vs 3 + 6	ns	0.0029	ns	0.0387
4 vs 5	ns	ns	ns	0.0644
8 vs 9	ns	ns	ns	ns
5 vs 7	ns	ns	ns	0.0656

Table 5: Impact of Treatment and Location on Cadmium Concentration in the Seed (1998)

trt	N - Forms	N - Placement	P - Placement	Melfort	Minnedosa	Morden	Indian Head
				ppb			
1	Urea	Spring Band	Side-Band	222	311	1258	827
2	Urea	Spring Band	Seed-Placed	224	278	1317	874
3	Amm Sulf	Spring Band	Side-Band	195	286	1260	763
4	Urea	Side-Band	Side-Band	179	291	1284	851
5	Amm Nitr	Side-Band	Side-Band	214	303	1229	790
6	Amm Sulf	Side-Band	Side-Band	206	300	1319	803
7	Urea+NBPT	Side-Band	Side-Band	196	288	1228	815
8	Urea	Spring Band	Spring Band	244	248	1282	844
9	Urea	Spring-Band (3-4" spread)	Spring Band	179	272	1232	.
10	Urea	Spring Band	Control-No P	201	299	1139	839

Table 6: Effect of N and P treatment and location on cadmium concentration of flax seed (1998)

Source	Melfort	Minnedosa	Morden	Indian Head
Treat	ns	ns	ns	ns
CV	18.75	14.85	8.63	16.07
Contrast				
Control vs rest	ns	ns	0.0068	ns
1 vs 2	ns	ns	ns	ns
1 vs 4	0.0632	ns	ns	ns
4 vs 7	ns	ns	ns	ns
4 vs 8	0.0059	0.0861	ns	ns
1 + 4 vs 3 + 6	ns	ns	ns	ns
4 vs 5	ns	ns	ns	ns
8 vs 9	0.0060	ns	ns	ns

5 vs 7	ns	ns	ns	ns

Effect of nitrogen placement varied with site and year, and were generally minor. In Melfort in 1996, Cd content was higher with side-banded urea than with pre-plant banded urea, when the P was side-banded while the opposite was true in 1998. In Melfort in 1996 and 1998 and in Morden in 1996, Cd content was lower when urea and P were spread over a 3-4" pre-plant banded than when they were spring-banded in a narrow band. The wide band may have been less available for crop uptake, may have led to a less vigorous plant, less able to take up Cd, or may have had a smaller effect on soil pH and osmotic strength due to the greater dilution of the band.

Summary

Location had the greatest impact on Cd concentration of flax, with 5-fold differences in concentration occurring between flax grown at Melfort and Morden. Differences were presumably due to the soil type, with high accumulations occurring in crops grown on soils derived from shales. Cadmium concentration was also high in flax grown at the Indian Head location. There was also considerable year to year variation, but rankings of location remained constant from year to year.

Effects of fertilizer management were minimal. At Melfort in 2 years and at Morden in 1 year, P application tended to increase Cd content, but this effect did not occur at the other location. Ammonium sulphate fertilizer tended to produce higher Cd concentrations than urea (3 site years) and a narrow pre-plant band of urea and P tended to produce a higher Cd concentration that if the N and P were spread over a wide band. However, in general, effects of fertilizer management on Cd content of flax were small in relation to the effect of location and environmental factors.

Field Study 2: Zinc Management Study

The objective was to determine the effects of source and placement of zinc on the yield of flax at one site in Manitoba. In 1996 and 1997, Cd concentration tended to be reduced with $ZnSO_4$ and increased with EDTA as compared to the control. The effect of $ZnSO_4$ was primarily due to lower Cd concentrations when the fertilizer was applied as a "sausage". With EDTA, the greatest effect was when the fertilizer was broadcast. On average, the "sausage" application of either fertilizer produced the lowest Zn concentration in 1996 and 1997.

Table 7: Effect of zinc fertilizer source and placement on cadmium content of flax at Morden (1996 -1998)

Treatment	Zinc Placement	Zinc Source	1996	1997	1998
1	Control	None	273	454	730
2	EDTA	Banded	308	516	698
3	EDTA	Broadcast	326	535	735
4	EDTA	Sausage	281	515	779
5	$ZnSO_4$	Banded	279	466	814
6	$ZnSO_4$	Broadcast	272	428	695
7	$ZnSO_4$	Sausage	221	416	742
Treatment			0.0016	0.0047	0.0151
SE			23.0	40.6	44.6
Contrast					
$ZnSO_4$ vs control			0.0008	0.0266	ns
EDTA vs control			0.0003	0.0078	ns
Broadcast vs band			ns	ns	ns
Broadcast vs sausage			ns	0.0522	ns
Band vs sausage			ns	0.0522	ns
$ZnSO_4$ broadcast vs band or sausage			ns	ns	ns

Field Study 3: Nitrogen and Phosphorus Rate

Experiments were conducted at three location in 1996, five locations in 1997 and four locations in 1998 to evaluate the impact of N and P rate on the yield and quality of flax. The results of this study are reported in the final report of "INCREASING FLAX YIELDS: A closer look at fertilizer utilization and weed management." by Guy Lafond and co-workers. Seed samples were collected at final harvest and analysed for cadmium content.

Effect of Location

As in the nitrogen and phosphorus placement study discussed before, location had a large effect on Cd concentration of flaxseed (Tables 8 and 9). Cadmium concentration was higher at Indian head, Lemberg and Scott, than at Melfort or Canora. Melfort and Canora produced flax with a Cd concentration below the 300 ppm level. There was also year to year variability, with Cd concentration at Canora averaging 284 ppm in 1997 and 169 ppm in 1998 while at Scott it averaged 576 ppm in 1997 and 918 in 1998.

Effect of Fertilization

Nitrogen by P interactions only occurred at Indian Head in 1998, Melfort in 1998 and Scott in 1997 (Table 8). At Melfort in 1998, an N*P interaction was related to a greater decrease in Cd with N fertilization occurring in the absence of P fertilization. At Indian Head in 1998, Cd concentration tended to increase with N application only where P was applied. At Scott in 1997, Cd decreased with N applications where no P or high levels P were applied, but increased when moderate levels of P were applied.

At the other site-years, no N *P interactions occurred and main effects of N and P were evaluated (Table 9). Nitrogen fertilization decreased flaxseed Cd concentration in flaxseed at Lemberg in 1996, Melfort in 1997 and 1998 and Canora in 1997. In contrast, applications of N increased Cd at Scott in 1998. Where N decreased Cd concentration, application of N increased flax seed yield, so the decrease in Cd concentration of flaxseed could have been related to biological dilution.

Phosphorus fertilization tended to increase Cd concentration in flax seed, with the increase being significant at Indian Head and Lemberg in 1997, Melfort in 1996, and Canora in 1997 and 1998. The increases in Cd concentration from P application may have been due to addition of Cd to the system in the P fertilizer, as P fertilizer contains some Cd as a contaminant. Alternately, P application may have influenced Cd phyto-availability indirectly, through effects on osmotic strength of the soil solution or impacts on plant growth and rooting.

Table 8: Effect of Nitrogen and Phosphorus Rate on Cadmium concentration in flaxseed at 5 locations over 3 years.

		Indian Head			Lemberg		Melfort			Scott		Canora	
Nitrogen	Phosphorus	1996	1997	1998	1996	1997	1996	1997	1998	1997	1998	1997	1998
0	0	885	745	729	855	669	289	218	292	769	903[2]	276	202
0	15	782	895	695	922	873	282	216	218	565	988	416	199
0	30	894	915	699	805	854	318	225	194	512	.	.	.
0	45	865	885	674	701	825	325	228	283	593	941	306	207
40	0	815	826	534	603	649	270	220	198	546	807	290	158
40	15	809	799	727	622	876	299	206	156	564	813	293	159
40	30	870	976	656	665	772	300	191	190	475	.	.	.
40	45	848	1044	968	676	817	300	205	203	562	726	303	209
80	0	740	775	680	797	816	253	195	167	475	1021	214	141
80	15	820	787	652	765	736	258	185	196	644	865	294	158
80	30	858	878	722	745	997	300	191	172	562	.	.	.
80	45	644	885	609	588	944	287	181	190	494	889	225	146
120	0	895	744	669	600	855	263	196	156	610	970	239	128
120	15	818	957	573	613	810	270	191	157	659	1076	262	170
120	30	924	1033	895	649	759	303	207	177	647	.	.	.
120	45	698	920	812	659	1027	295	214	166	537	1015	290	154
Mean		827	879	706	704	830	288	204	195	576	918	284	169
SEM		95.5	58.3	86.5*[1]	80.4	76.2	19.1	14.8	18.6*	56.3*	77.7	34.4	12.6

[1] Indicates significant NxP interaction

[2]Phosphorus rates were 0, 20 and 40 at Scott in 1998 and at Canora in 1997 and 1998

Table 9: Mean effects of N and P on Cd concentration of flaxseed at 5 locations over three years.

		Indian Head			Lemberg		Melfort			Scott		Canora	
Nitrogen	Phosphorus	1996	1997	1998	1996	1997	1996	1997	1998	1997	1998	1997	1998
0		857	860	699	821	805	303	222	247	610	944	333	202
40		829	911	721	642	779	292	205	187	536	782	295	175
80		758	831	666	724	874	275	188	181	544	925	244	148
120		828	914	737	630	863	283	202	164	613	1021	264	151
SEM		44.4	29.2	43.2	40.2**	38.1	9.5	7.4*	9.3***	28.2	45.8**	19.9*	7.25*
	P												
	0	835	772	653	714	747	269	207	203	600	925[1]	255	157
	15	809	860	662	730	824	277	200	182	608	935	316	171
	30	886	950	743	716	846	305	204	183	549	.	.	.
	45	742	934	766	656	903	302	207	210	547	893	281	178
SEM		46.9	29.2***	43.2	40.2	38.1*	9.5*	7.4	9.3*	28.2	40.6	17.2***	6.28*

[1]Phosphorus rates were 0, 20 and 40 at Scott in 1998 and at Canora in 1997 and 1998

Field Study 4: Nitrogen, Phosphorus, Potassium and Sulphur Study.

Description of Study:
Experiments were conducted at three location in 1996 and 1997 and two locations in 1998 to evaluate the impact of N, P, K and S of flax. The variety used was Norlin, with a seeding rate of 62 kg/ha or 1 bus/ac. Treatments were combinations of urea at 120 kg N/ha (soil and fertilizer N), MAP at 35 kg P_2O_5/ha, ammonium sulphate at 20 kg S/ha and potassium chloride at 35 kg K_2O/ha. All fertilizers were commercial grade.

Objective(s): To determine the interactive effects of nitrogen, phosphorus, potassium and sulfur on Cd concentration of flaxseed at three locations, Melfort, Lemberg and Indian Head.

Effect of Location
As in the previous experiments, location had a large effect on Cd concentration of flaxseed (Tables 10). Cadmium concentration was higher at Indian Head and Lemberg than at Melfort. Melfort produced flax with a Cd concentration below the 300 ppm level. There was also year to year variability, with Cd concentration at Lemberg averaging 679 in 1996 and 829 in 1997, while at Melfort it was twice as high in 1996 (288) as in 1998 (139).

Table 10 : Cadmium content of flax seed (ppb) as influenced by N, P, K and S fertilizers at three locations over 3 years.

Treatment	Indian Head			Lemberg		Melfort		
	1996	1997	1998	1996	1997	1996	1997	1998
N	739	809	721	709	704	260	241	139
N and P	892	807	651	646	998	263	226	127
N, P and K	734	878	701	682	799	263	274	134
N, P and S	834	850	793	669	978	274	226	141
N,P,K and S	985	832	785	634	878	302	282	128
Control	791	670	813	733	619	366	280	166
Mean (Site-Year)	829	808	744	679	829	288	255	139
Mean (Site)		794		754			227	
Treatment Effects	ns	0.0013	ns	ns	0.0028	0.0070	0.0188	ns
Contrasts								
N, P, K, S vs none	0.0591	0.0008	ns	ns	0.0089	0.0150	ns	0.0242
N vs N, P, K, S	0.0202	ns	ns	ns	0.0619	0.0650	0.0519	ns
N vs N and P	ns	ns	ns	ns	0.0038	ns	ns	ns
N and P vs N, P, K	ns	0.0968	ns	ns	0.0352	ns	0.0270	ns
N and P vs N, P,S	ns	ns	ns	ns	ns	ns	ns	ns
SE	118.7	28.4	100.5	57.3	ns	16.9	14.1	18.6

Effect of Fertilizers
Fertilizer applications had a significant effect on Cd concentration of flaxseed in 6 out of the 8 site-years, when examined by contrast analysis. Application of N tended to have the greatest

effect on Cd concentration. However, application of N, P, K and S led to higher Cd concentration than application of N alone at Indian Head in 1996 and Lemberg and Melfort. In contrast, application of N,P,K and S produced lower Cd than application of N alone at Lemberg in 1996. Phosphorus had little effect on Cd concentration in flaxseed, increasing its concentration only in Lemberg in 1997. At 5 out of the other 7 sites, the concentration of Cd in flaxseed was numerically lower with application of N and P than with application of N alone.

Effects of K were also mixed, with N, P, and K having higher Cd concentration than N and P at Indian Head and Melfort in 1997, but lower concentration than N and P at Lemberg in 1997. Generally, there was no effect of K. There was also no influence of S on Cd concentration
If significant differences occurred at Indian Head and Lemberg, fertilizer applications increased Cd concentration as compared to the control. In contrast, at Melfort, Cd concentration was lower with fertilizer applications than in the control. It may be that in soils with higher amounts of Cd in the soil, application of fertilizers increase Cd uptake by mobilizing soil reserves of Cd, increasing the supply to the plant. In contrast, in soils where the amount of Cd in the soil is lower, fertilizers reduce Cd concentration in the plant by dilution when plant yield increases.

Study 6: Influence of N, P, K and S on Cadmium Concentration of Flaxseed (Scott and Canora)

An expanded set of N, P, K and S rates were applied in experiments at Scott and Canora 1997 and 1998 to more fully evaluate the impact of N, P, K and S on Cd concentration of flax. Treatments were combinations of rates urea, MAP, ammonium sulphate and potassium chloride. All fertilizers were commercial grade.

Table 12: Influence of N , P, K and S rates on Cd concentration (ppb) in flaxseed at Scott in 1997

			N Rate (kg ha^{-1})				Mean Across N rates
P	K	S	0	40	80	120	
0	0	0	801	668	672	618	690
0	0	20	739	730	652	573	673
0	24	0	720	703	761	778	740
0	24	20	882	647	746	801	769
Mean of 0 P			785	687	708	692	718
20	0	0	735	686	626	782	707
20	0	20	687	668	736	810	725
20	24	0	650	763	801	990	801
20	24	20	725	793	802	813	783
Mean of 20 P			699	727	741	849	754
Mean of 0 K			740	688	672	696	699
Mean of 24 K			744	726	777	845	773
Mean of 0 S			726	705	715	792	734
Mean of 20 S			758	710	734	749	738

As in other studies, impact of location was large, with Cd concentration at Scott being approximately 3 times that at Canora (Tables 12-17). At Scott in 1997, P application increased Cd levels in flaxseed slightly (Tables 12 and 13). While there was no simple effect of N on Cd concentration, there was an N*P interaction, with N application leading to lower Cd concentrations in the absence of P and higher Cd concentrations when P was applied. The N fertilizer possibly led to increased uptake of the Cd contained in the P fertilizer. Potassium increased Cd concentration in flaxseed, and an N*K interaction again indicated decreasing Cd concentration with applications of N in the absence of K fertilizer and increasing Cd concentration when K was applied. Chloride is believed to form Cd complexes which increase the availability of Cd for plant uptake. This may lead to an increased supply of Cd, which compensates for dilution and increases the concentration in the tissue when rooting and tranpirative mass flow are increased by increased plant growth from applied N. Sulphur had no effect on Cd concentration in flaxseed. In 1998, the only significant effect was an increase in Cd concentration with K application (Tables 14 and 15). Therefore, the most consistent fertilizer effect at Scott was the effect of KCl application in increasing Cd concentration in flax.

Table 13: Influence of N , K and S rates on Cd concentration (ppb) in flaxseed at Scott in 1998

		N rate				Mean Across N Rates
K	S	0	40	80	120	
0	0	916	894	927	793	882
0	20	804	834	851	782	818
0	40	779	690	821	937	807
Mean (0 K)		833	806	866	837	836
36	0	946	825	812	902	871
36	20	826	819	897	952	873
36	40	747	741	708	789	746
Mean (36 K)		840	795	806	881	830
72	0	888	912	1034	820	914
72	20	1026	913	843	960	936
72	40	907	901	1053	917	945
Mean (72 K)		940	909	977	899	931
Mean of 0 S		917	877	925	838	889
Mean of 20 S		885	856	864	898	876
Mean of 40 S		811	777	861	881	833

Table 14: Results from Proc Mixed analysis of variance for effects of N, P, K and S on Cd concentration of flaxseed at Scott, 1997-98.

Source	1997			1998		
	DF	P-value	SE	DF	P-value	SE
N	3	ns	48.3	3	ns	36.6
P	1	0.0926	45.9	0	-	-
N*P	3	0.0017	52.8	0	-	-
K	1	0.0007	45.9	2	0.0012	34.5
N*K	3	0.0724	52.8	6	ns	50.5
P*K	1	ns	48.3	0	-	-
N*P*K	3	ns	60.07	0	-	-
S	1	ns	45.9	2	ns	34.5
N*S	3	ns	52.8	6	ns	50.5
P*S	1	ns	48.3	0	-	-
N*P*S	3	ns	60.7	0	-	-

K*S	1	ns	48.3	4	ns	45.8
N*K*S	3	ns	60.7	12	ns	78.4
P*K*S	1	ns	52.8	0	-	-
N*P*K*S	3	ns	74	0	-	-

Table 15: Influence of N , K and S rates on Cd concentration (ppb) in flaxseed at Canora in 1997

		N rate				Mean Across N Rates
K	S	0	40	80	120	
0	0	320	241	174	188	231
0	20	304	200	228	224	239
0	40	268	294	215	191	242
Mean (0 K)		297	245	205	201	237
36	0	274	245	212	213	236
36	20	280	242	219	216	239
36	40	274	343	241	240	274
Mean (36 K)		276	276	224	223	250
72	0	314	241	222	233	253
72	20	323	240	238	245	261
72	40	242	327	263	214	261
Mean (72 K)		293	269	241	231	258
Mean of 0 S		302	242	203	211	240
Mean of 20 S		302	227	228	228	246
Mean of 40 S		261	321	239	215	259

Table 16: Influence of N , K and S rates on Cd concentration (ppb) in flaxseed at Canora in 1998

		N rate				Mean Across N Rates
K	S	0	40	80	120	
0	0	255	263	147	270	234
0	20	213	283	237	242	244
0	40	211	253	268	211	236
Mean (0 K)		226	266	218	241	238
36	0	279	249	222	279	257
36	20	229	171	289	261	238
36	40	204	285	181	165	209
Mean (36 K)		237	235	231	235	235
72	0	200	223	274	260	239

72	20	277	184	219	256	234
72	40	200	243	215	270	232
Mean (72 K)		225	216	236	262	235
Mean of 0 S		244	245	214	270	243
Mean of 20 S		239	213	249	253	238
Mean of 40 S		205	260	221	215	225

Nitrogen, K and S all influenced Cd concentration in flaxseed at Canora in 1997 (Tables 15-17). Nitrogen decreased and K increased Cd concentration of flaxseed. Sulphur increased Cd concentration of flaxseed, when averaged over N levels, but there was an N*S interaction, with S applications decreasing Cd in the absence of applied N, but increasing Cd concentration when N was applied. In 1998, fertilizer application did not influence Cd concentration

Table 17: Results from Proc Mixed analysis of variance for effects of N, , K and S on Cd concentration of flaxseed at Canora, 1997-98.

Source	1997			1998		
	DF	P-value	SE	DF	P-value	SE
N	3	0.0001	8.16	3	ns	44.7
K	2	0.0562	7.34	2	ns	44.1
N*K	6	ns	13	6	ns	49
S	2	0.0798	7.34	2	ns	44.1
N*S	6	0.0001	13	6	ns	49
K*S	4	ns	11.42	4	ns	47.5
N*K*S	12	ns	21.8	12	ns	60.2

OVERALL SUMMARY

When information was examined from all experiments, location had the greatest impact on cadmium concentration, with concentrations ranging by more 5-fold from site to site. Year to year variability was also substantial.

Impact of fertilizers will be through their influence on plant growth, soil chemistry and with some sources, the addition of Cd to the system. Therefore, effects will vary depending on factors such as if the nutrient is deficient or sufficient, the size of the yield response that occurs, the ability of the soil to buffer changes in pH or osmotic potential from the fertilizer application and the level of background Cd present for plant uptake. Fertilizer applications influenced cadmium concentration in flax at some locations, although effects were relatively small compared to that of location. Where fertilizer effects occurred, application of N generally led to lower Cd concentration, although increases sometimes occurred. Nitrogen may reduce Cd concentration through dilution when Cd concentration in the medium is low and crop production increases with N application. In contrast, N may sometimes mobilize Cd through osmotic effects or microsite acidification, leading to increases in Cd concentration. This appeared to happen more frequently when N was applied in combination with other nutrients. Placement of N had little effect on Cd concentration. Use of ammonium sulphate sometimes led to higher concentrations of Cd than did other N sources. The greater acidifying effect of ammonium sulphate could have enhanced Cd availability.

Phosphate fertilizer contains Cd at varying levels, depending on its source. Therefore, in the long term, application of Cd could increase Cd content of the soil and encourage higher Cd concentration in crops. However, the short-term effect of P was small in these trials. Where P had an influence on Cd concentration, it generally led to higher levels. However, the effect was inconsistent.

In other studies, Zn has been shown to reduce Cd concentration of crops. However, in this study, only "sausage" application of $Zn\ SO_4$ decreased Cd concentration, while application of EDTA-chelated Zn increased Cd concentration of flaxseed. Sulphur did not generally influence Cd concentration. Potassium chloride tended to increase Cd concentration in flaxseed and the effect was somewhat more consistent than the effects of the other fertilizer materials tested. Chloride can form complexes with Cd in the soil, increasing its mobility and enhancing its availability for crop uptake.

Based on the results of these studies, it appears that site selection is the most important management factor that can be used to reduce Cd concentration in flax. Flax that is intended for entry into the food market, where low Cd level is desired, should be produced on soils that have been shown to produce low-Cd crops. Application of N to optimize crop yield should not lead to higher Cd levels. Application of P or KCl could lead to higher Cd levels, but the effect is small relative to the impact of location. In an area marginal for production of low-Cd flax, over-fertilization or use of "just-in-case" applications of these nutrients should be avoided. In some studies, Zn has been shown to decrease Cd in flax, but only a "sausage" application of $ZnSO_4$ was effective at the single location in this study. However there was no yield response to Zn application at this location, so it is possible that Zn application may reduce Cd concentration on locations where Zn level in the soil is marginal or deficient.