THE EFFECT OF TILLAGE SYSTEM AND PRECEDING CROP ON PHOSPHORUS RESPONSE OF FLAX

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Introduction and Literature Review

Reduced tillage systems are becoming increasingly popular on the prairies, to conserve soil moisture, increase crop yield potential, improve soil quality and reduce time, labour and equipment costs in farming operations. Reducing tillage also has important implications for nutrient management. With reduced tillage, moisture relations, distribution of nutrients in the profile, deposition of organic residues and the type and activity of soil micro-organisms will change as compared to a conventional tillage system (Grant and Bailey 1993). This will impact directly on nutrient availability and on fertilizer management decisions. While many research studies have evaluated impact of tillage systems on N fertility requirements, there has been little information collected on the impact of tillage management on P phytoavailability.

Early season P supply is critical to determination of optimum crop yield. Withholding P during early plant growth will limit crop production and cause a restriction in crop growth from which the plant may not recover. Phosphorus limitation later in the season has a much lower impact on crop production than limitations experienced early in growth. No-till systems reduce early season soil temperature and can increase soil compaction (Grant and Lafond 1994), which may reduce the availability of phosphorus during early growth. Low P supply and slow root growth may combine to cause severe P stress early in the season when plant demand for P will outstrip the soils ability to supply the nutrient. This may occur more frequently under reduced tillage, where the soil is slightly slower to warm up in the spring and where bulk densities in the soil surface may be increased to some extent (Grant and Lafond 1994). However, it may be that in soils with a history of phosphorus fertilization, as most of our soils have now, starter phosphorus to optimize crop yield may be less important than in the past, if management practices encourage availability of residual phosphorus from the soil. Information on the impact of tillage system and past phosphorus fertilizer management on phosphorus response of crops is limited.

Canola and wheat are the two major annual crops in the Canadian prairies, while flax is also important. Flax and wheat tend to respond very well to reduced tillage systems, frequently producing higher yields under no-till as compared to conventional till management (Lafond et al. 1993). According to both research trials (Lafond et al. 1993) and producer experience, canola may not respond as beneficially to no-till management as cereal crops or flax. If part of the reason for lower relative yield of canola under no-till is the change in nutrient dynamics, optimization of soil fertility could lead to significantly higher canola yields.

While flax production is lower than that of canola and wheat, it is likely to expand in the future. Production of flax was limited and prices volatile because of the size of the industrial oil market. While some flax is used for human consumption, the instability and short shelf life of the product reduced the widespread of linseed oil in the human diet. A plant breeding program has recently led to the development of Solin, a category of flax with oil characteristics similar to those of sunflower. Solin cultivars produce an oil that resists auto-oxidation and has a longer shelf life. These characteristics have made solin oil sought-after in the edible oil market. In addition, there is increasing movement of flaxseed into the health food market, because of reported beneficial effects on the nature and levels of blood cholesterol. The expanding market for flaxseed, combined with the current low prices for cereal crops, the removal of the Western Grain Transportation Subsidy, and the increasing incidence of fusarium head blight and wheat midge, point to an increase in future flax acreage in western Canada.

Canola and wheat have a high demand for crop nutrients, including phosphorus (Grant and Bailey 1993b). Deficiencies of P are common and frequently limit crop yield. Therefore, proper P fertilization is important in optimising crop production. Although canola requires a large amount of P for growth, maximum responses are often attained at lower rates of P than for wheat, corn or barley. Kalra and Soper (1968) evaluated the efficiency of a number of crops in absorbing soil and fertilizer phosphorus, under greenhouse conditions. Rapeseed and flax used about equal amounts of soil P, but rapeseed absorbed fertilizer P in large amounts. Rapeseed was much more effective than flax in extracting fertilizer P. This is because rapeseed, a nonmycorrhizal plant, could modify its root structure and root hair number, proliferating roots in fertilizer reaction zones and decreasing pH in the rhizosphere. However, rapeseed (canola) is sensitive to damage from seed-placed P and quantities of P required to optimize yield may lead to seedling damage.

Phosphorus fertilization of flax can be problematic, since flax is very sensitive to seed-placed applications of monoammonium phosphate (Nyborg and Hennig 1969). Banded applications of P fertilizer are not generally used effectively by flax unless they are positioned within 2.5 to 5.0 cm of the seed-row (Sadler 1980) and broadcast applications of P tend not to increase flax seed yield (Grant and Bailey 1993). Therefore, unless a producer has access to seeding equipment capable of side-banding fertilizer, P fertilization of flax is frequently ineffective. Most of the studies conducted on P fertilization of flax were conducted under conventional tillage. Cooperative studies being conducted by Agriculture and Agri-Food Canada, coordinated by Guy Lafond (Pers. Comm.), show responses of no-till flax to P fertilizer were generally quite low, in the order of 0 to 2 bu acre, which was generally not statistically significant. In 14 site years of research in Manitoba and Saskatchewan, the P response of the "best" treatment in the experiment exceeded 3 bu/acre in only 3 instances. Producers frequently avoid P application in flax and increase the P supply in the preceding crops, in order to supply residual P for use by the subsequent flax crop.

Mycorrhizae are fungi which form associations with certain crops under low-P situations, enhancing the uptake of P by the crop. Tillage disrupts the mycorrhizal network. Research at Guelph (Miller 1998) and Agassiz (Bittman et al. 1998) showed that corn produced on summer fallow or under intense tillage was restricted in its ability to access P, while corn which followed a mycorrhizal crop, particularly under no-till, showed improved early season P nutrition. The greater P absorption is largely a result of the undisrupted mycelium present in an undisturbed soil. The mycelium remains viable over extended periods in frozen soil and so can acquire P from the soil and deliver it to the plant immediately upon becoming connected to a newly developing root system in the spring. Phosphorus status of the crop in the first 4-6 weeks of growth has a major impact on final crop yield. Flax is a highly mycorrhizal crop. It is possible mycorrhizal associations could be responsible both for part of the positive response that flax shows in no-till systems and for the limited P response observed in recent studies. If so, P fertility requirements in flax could be greatly affected by tillage system and by whether the preceding crop was mycorrhizal or not. Phosphorus fertilization could possibly be reduced or eliminated in flax grown in no-till following a mycorrhizal crop and optimized in flax grown on summer fallow, after a non-mycorrhizal crop, or under conventional tillage management. By more clearly defining the P requirements of flax, canola and wheat grown under different management systems, we may be able to reduce inputs while maintaining or improving crop yield and quality.

While effect of P on crop yield are important, it is also important to consider effects on crop quality. Cadmium (Cd) is a heavy metal present in soils, crops and phosphate fertilizers. Concern about food-chain transfer of Cd has resulted in (a) the World Health Organization setting a maximum provisional tolerable intake limit for an adult at 60 to 70 :g Cd per day (World Health Organization 1972) and (b) the Codex Alimentarius Commission of FAO/WHO proposing a limit on the concentration of Cd in cereal grains and oilseeds traded on the international markets. Although oilseed flax is generally grown for industrial purposes, a portion of the crop is used for human consumption. Cadmium levels in flaxseed can exceed 300 mg kg^{-1} (Marquard et al. 1990). Promotion of flax as a health food may increase the amount of flax in the human diet. Therefore, the relatively high level of Cd in flaxseed is of concern.

Phosphate fertilizers usually contain Cd in varying concentrations, reflecting the Cd content of the rock from which the fertilizer was derived. Phosphorus fertilizer may also influence Cd availability through its effects on soil pH, ionic strength, Zn concentration and plant growth. Preceding crop (Oliver et al. 1993) and tillage system (Brown 1998) may also influence Cd concentration of crops. However, information on the interactive effects of tillage system, preceding crop and P management on Cd content of crops is lacking. It may be possible to reduce the Cd content of flax while maintaining P sufficiency and crop yield by supplying P for flax by high applications in the preceding crop.

Objectives

1) To determine the impact of tillage system on P fertilizer response of canola and wheat.
2) To determine the yield response of flax to P fertilizer application, as influenced by preceding crop and tillage system and level of P fertilization in preceding crop.
3) To determine the effect of tillage system, preceding crop and P fertilizer management on Cd content of flax.
4) To determine the degree of mycorrhizal activity in flax, as affected by preceding crop and tillage system
5) To determine the early season accumulation of P by flax as influenced by preceding crop and tillage system

Results and Discussion

1999 Canola and Wheat

Two field locations were selected north of Brandon. Both were on Newdale clay loam soils, one of which had been under no-till for the past 6 years and one of which had been under conventional tillage. Extremely wet spring conditions delayed seeding until June 15 on the conventional tilled site and June 24 on the no-till site. Cool and wet condition during the summer led to slow crop development, however an open fall allowed for successful harvest of the crops.

Table A-1: Effect of P application and tillage system on biomass yield (kg/ha) at 5 weeks for canola and wheat at two locations (1999)

	Canola				Wheat			
	Research Centre		MZTRA		Research Centre		MZTRA	
P_2O_5	CT	NT	CT	NT	CT	NT	CT	NT
0	1135	993	1922	2150	1636	1631	1221	1655
25	1265	1382	2169	2317	1583	1618	1925	2470
50	1709	1422	2439	2640	1708	1914	1967	2320
Mean	1370	1265	2177	2369	1642	1721	1704	2148

Table A-2: Statistical analysis using Proc Mixed for effects of phosphorus fertilizer and tillage system on biomass yield of canola and wheat at two sites in 1999.

		Canola				Wheat			
Source	DF	Research Centre		MZTRA		Research Centre		MZTRA	
		P-value	SE	P-value	SE	P-value	SE	P-value	SE
Phosphorus	2	0.0283	174	0.0034	99	ns	186	0.0002	137
Tillage	1	ns	202	ns	89	ns	239	0.0425	122
Phosphorus*Tillage	2	ns	242	ns	140	ns	262	ns	193

Phosphorus fertilization increased biomass yield of canola at both locations and of wheat at the MZTRA . With canola, yield increased with increasing P level to 50 kg/ha at both locations, while with wheat, the yield increased only with the first 25kg/ha of P_2O_5. Tillage did not influence biomass yield of canola, but biomass yield of wheat at the MZTRA was higher with no-till than conventional till, in spite of the very wet and cold conditions experience during this summer. No tillage by P interactions occurred, indicating that P response patterns were similar under no-till and conventional till.

Table A-3: Effect of P application and tillage system on grain (kg/ha) for canola and wheat at two locations (1999)

	Canola				Wheat			
	Research Centre		MZTRA		Research Centre		MZTRA	
P_2O_5	CT	NT	CT	NT	CT	NT	CT	NT
0	940	951	413	629	1128	1429	905	598
25	1008	1090	618	754	1194	1497	629	751
50	1155	985	600	818	1275	1549	630	673
Mean	1034	1009	544	734	1199	1492	721	674

Seed yields were low, due to late seeding and adverse weather throughout the growing season. Seed yield of canola was not significantly affected by P application or tillage system at the research centre site (Table A3 and A4), but was increased by P application on the MZTRA site. Canola seed yield also tended to be higher with NT than CT at the MZTRA site, but there was no tillage by P interaction, indicating that the crop response to P was similar under the two tillage systems. Wheat grain yield tended to increase with P application on the research centre site ($p<0.0780$) and tended to be higher under NT than CT ($p<0.0810$), however on the MZTRA , there was no significant effect of either P or tillage on wheat grain yield.

Table A4: Statistical analysis using Proc Mixed for effects of phosphorus fertilizer and tillage system on grain of canola and wheat at two sites in 1999.

		Canola	Wheat

Source	DF	Research Centre		MZTRA		Research Centre		MZTRA	
		P-value	SE	P-value	SE	P-value	SE	P-value	SE
Phosphorus	2	ns	83.8	0.0003	65.7	0.0780	77.2	ns	142.5
Tillage	1	ns	74.8	0.0701	69.7	0.0810	98.8	ns	116.3
Phosphorus*Tillage	2	ns	106.3	ns	78.7	ns	109.2	ns	201.5

2000 Canola and Wheat

Biomass yield of both wheat and canola at 5 weeks was higher under CT than NT at both research locations in 2000 (Tables B1 and B2). This differs substantially from the results in 1999, where tillage system had little effect on biomass yield, and if differences occurred, yields were higher with NT than CT. In 1999, seeding was delayed substantially due to excess moisture. The late seeding may have led to generally warmer soil temperatures, favouring NT as compared to the early seeding conditions in 2000. Conditions throughout the summer in 2000 were wet and cold. Saturated conditions in the root zone may have led to poor aeration and restricted yield under NT, particularly on the Research Centre Farm, where NT systems were relatively newly established.

Phosphorus application increased biomass yield of canola on the MZTRA , but not at the Research Centre Farm. Biomass yield of wheat was increased with P application at both locations. A P by Tillage interaction occurred for canola production at the MZTRA , where biomass yield increased with P application to a greater extent under CT than under NT.

Table B1: Effect of P application and tillage system on biomass yield (kg/ha) at 5 weeks for canola and wheat at two locations (2000)

	Canola				Wheat			
	Research Centre		MZTRA		Research Centre		MZTRA	
P_2O_5	CT	NT	CT	NT	CT	NT	CT	NT
0	1308	690	720	539	1075	629	955	807

25	1474	835	1033	786	1322	747	1244	908
50	1493	746	1359	853	1420	857	1353	1009
Mean	1425	757	1037	726	1272	744	1184	908

Table B2: Statistical analysis using Proc Mixed for effects of phosphorus fertilizer and tillage system on biomass yield of canola and wheat at two sites in 2000.

		Canola				Wheat			
Source	DF	Research Centre		MZTRA		Research Centre		MZTRA	
		P-value	SE	P-value	SE	P-value	SE	P-value	SE
Phosphorus	2	ns	107	0.0001	67	0.0001	50	0.0003	48
Tillage	1	0.0001	102	0.0266	75	0.0057	54	0.0001	39
Phosphorus*Tillage	2	ns	120	0.0690	95	ns	70	ns	68

Seed yield of both canola and wheat was higher under CT than NT, with the effect being greater on the Research Centre Farm than on the MZTRA (B3 and B4). Seed yield was also increased with P fertilization on the MZTRA , but not at the Research Centre Farm. There were no differences in response to P application under the two tillage systems. Poor seed yield under NT may relate to the persistent wet conditions experienced in 2000.

Table B3: Effect of P application and tillage system on grain (kg/ha) for canola and wheat at two locations (2000)

	Canola		Wheat	
	Research Centre	MZTRA	Research Centre	MZTRA

P_2O_5	CT	NT	CT	NT	CT	NT	CT	NT
0	1805	1159	1527	1195	3952	2990	4081	3856
25	1966	1020	1642	1381	4181	2874	4248	4003
								50
Mean	1862	1071	1644	1329	4070	3025	4312	3995

Table B4: Statistical analysis using Proc Mixed for effects of phosphorus fertilizer and tillage system on grain yield of canola and wheat at two sites in 2000.

		Canola				Wheat			
Source	DF	Research Centre		MZTRA		Research Centre		MZTRA	
		P-value	SE	P-value	SE	P-value	SE	P-value	SE
Phosphorus	2	ns	137.0	0.0314	91.6	ns	136.4	0.0231	107.8
Tillage	1	0.0132	146.0	0.0818	99.1	0.0033	157.0	0.0737	93.2
Phosphorus*Tillage	2	ns	163.0	ns	120.2	ns	193.0	ns	146.5

Effects on Nutrient Content of Canola and Wheat - Combined for 1999 and 2000

Nitrogen concentration in canola tissue at the Research Centre was lower under NT than CT, indicating reduced early season availability of N with reduced tillage (Table B5). As biomass yield at five weeks was lower with NT than CT, the reduced nutrient availability may have been restricting plant growth. At the MZTRA , N concentration was not affected by tillage.

B5 : Canola tissue N, P, Zn and Cd concentration as influenced by tillage system and P fertilization at two locations (combined for 1999 and 2000).

	Tissue N (%)		Tissue P (ppm)		Tissue Zn (ppm)		Tissue Cd (ppb)	
Phosphorus	Research Centre							
kg ha^{-1}	CT	NT	CT	NT	CT	NT	CT	NT
0	5.29	5.20	0.454	0.447	31.5	30.6	740	760
25	5.28	4.90	0.483	0.474	27.6	27.0	911	861
50	5.39	4.80	0.525	0.483	26.5	24.6	1007	868
Mean	5.32	4.97	0.487	0.468	28.5	27.4	886	830
	MZTRA							
0	5.19	5.22	0.334	0.333	36.0	31.7	584	622
25	5.09	5.22	0.388	0.361	30.2	28.5	664	649
50	5.02	5.14	0.409	0.411	27.1	26.9	668	709
Mean	5.10	5.19	0.377	0.368	31.1	29.0	639	660
	Analysis of Variance							
	Research Centre	MZTRA	Research Centre	MZTRA	Research Centre	MZTRA	Research Centre	MZTRA
Phosphorus	1.59	1.2	14.78****	36.12****	23.21****	26.28****	15.39****	5.35**
Tillage	12.82**	0.59	4.22	0.96	1.08	0.69	0.78	0.09
P*Tillage	2.36	0.21	1.93	1.56	0.33	2.35	2.35	0.7
	P-values							
Low P vs No P	ns	ns	0.0067	0.0001	0.0001	0.0001	0.0003	0.0457
No P vs High P	ns	ns	0.0001	0.0001	0.0001	0.0001	0.0001	0.0018
Low P vs High P	ns	ns	0.0092	0.0002	0.0441	0.0149	ns	ns
					Standard Error Values			
SE P	0.415	1.08	0.054	0.084	5.14	6.24	247	39.7
SE Tillage	0.413	1.08	0.054	0.084	5.15	6.34	248	51.8
SE P*Tillage	0.423	1.08	0.055	0.084	5.2	6.39	250	56.1

Nitrogen concentration in wheat tissue at five weeks was also lower under NT than under CT at the Research Centre (Table B6). As biomass yield was also lower under NT than CT, it appears that early season N availability ma have been restricted by NT at this location. Tillage system did not influence N concentration in wheat tissue at the MZTRA , but at both locations there was a reduction in N concentration with P fertilization. This may reflect dilution due to the increased biomass yield with P fertilization. In canola, P fertilization did not affect N concentration (Table B5)

Phosphorus concentration in the tissue was not influenced by tillage system at either location in either canola or wheat. Concentration of P in canola and wheat was increased by application of P fertilizer at both locations (Table B5), but concentration of P in wheat tissue was only increased by the higher rate of P fertilization at the Research Centre (Table B6).

B5 : Wheat tissue N, P, Zn and Cd concentration as influenced by tillage system and P fertilization at two locations (combined for 1999 and 2000).

	Tissue N (%)		Tissue P (ppm)		Tissue Zn (ppm)		Tissue Cd (ppb)	
Phosphorus	Research Centre							
kg ha^{-1}	CT	NT	CT	NT	CT	NT	CT	NT
0	4.32	4.03	0.319	0.326	19.9	20.5	157	148
25	4.26	3.92	0.323	0.322	18.9	18.0	179	150
50	4.13	3.93	0.331	0.337	17.8	17.0	174	144
Mean	4.24	3.96	0.324	0.328	18.9	18.5	170	147
	MZTRA							
0	4.57	4.30	0.298	0.296	22.4	21.1	107	85
25	4.14	4.16	0.303	0.298	18.0	16.8	115	117
50	4.06	4.19	0.305	0.313	20.8	16.4	140	104
Mean	4.26	4.22	0.302	0.302	20.4	18.1	121	102
	Analysis of Variance							
	Research Centre	MZTRA	Research Centre	MZTRA	Research Centre	MZTRA	Research Centre	MZTRA
Phosphorus	2.23	9.98****	3.10*	2.91	14.05****	3.42*	0.51	6.39**
Tillage	5.83*	0.12	0.27	0.00	0.20	2.00	1.63	1.45
P*Tillage	0.51	3.68*	0.37	0.93	1.03	0.58	0.54	3.15*
	P-values							
Low P vs No P	ns	0.0004	ns	ns	0.0011	0.0139	ns	0.0094
No P vs High P	0.0386	0.0001	0.0343	0.0224	0.0001	0.0657	ns	0.0011
Low P vs High P	ns	ns	0.0343	0.093	0.0805	ns	ns	ns
	Standard Error Values							
SE P	0.106	0.903	0.023	0.039	1.58	2.14	44.5	29.9
SE Tillage	0.112	0.903	0.023	0.04	1.59	1.06	45	30.4
SE P*Tillage	0.127	0.906	0.024	0.04	1.65	2.48	45.8	31.1

Zinc concentration in canola and wheat tissue was not influenced by tillage at either location, but was reduced by application of P fertilizer (Tables B5 and B6). Cadmium concentration in canola and wheat tissue was not influenced by tillage system, but Cd concentrate in canola tissue was increased with P fertilization at both locations, while Cd concentration in wheat tissue was increased by P fertilization at the MZTRA , with the effect being greater under CT than ZT.

Canola seed N concentration was not influenced by tillage or P at wither location (Table B7), while grain N in wheat was reduced slightly by P application of P, possibly due to dilution (Table B8). Phosphorus concentration in both canola seed and wheat grain was increased by P application. Canola seed concentration of P was higher under NT than CT at the Research Centre, likely because seed yield was reduced by NT.

B7: Canola seed N, P, Zn and Cd as influenced by tillage system and P fertilization at two locations (combined for 1999 and 2000).

	Seed N (%)	Seed P (ppm)	Seed Zn (ppm)	Seed Cd (ppb)
Phosphorus	Research Centre			

kg ha^{-1}	CT	NT	CT	NT	CT	NT	CT	NT
0	3.52	3.53	0.581	0.606	34.4	31.3	83.8	81.4
25	3.52	3.48	0.615	0.666	30.4	31.3	90.0	91.1
50	3.47	3.49	0.655	0.683	29.0	28.0	101.7	94.0
Mean	3.50	3.50	0.617	0.651	31.2	30.2	91.8	88.8
	MZTRA							
0	3.63	3.71	0.522	0.537	38.4	34.7	80.0	65.9
25	3.67	3.58	0.549	0.535	36.3	35.4	79.5	80.2
50	3.76	3.65	0.612	0.604	31.4	31.3	85.8	83.5
Mean	3.69	3.65	0.561	0.559	35.4	33.8	81.7	76.5
	Analysis of Variance							
	Research Centre	MZTRA	Research Centre	MZTRA	Research Centre	MZTRA	Research Centre	MZTRA
Phosphorus	0.69	0.84	31.89****	30.64****	23.02****	13.00****	13.71****	2.27
Tillage	0.01	0.67	18.87****	0.04	2.04	1.23	0.62	1.2
P*Tillage	0.35	1.48	ns	1.00	4.47*	1.46	0.83	0.99
	P-values							
Low P vs No P	ns	ns	0.0001	ns	0.0021	ns	0.0164	ns
No P vs High P	ns	ns	0.0001	0.0001	0.0001	0.0001	0.0001	0.0373
Low P vs High P	ns	ns	0.0035	0.0001	0.0007	0.0001	0.0079	ns
	Standard Error Values							
SE P	0.101	0.12	0.018	0.033	1.17	1.86	13.1	10.17
SE Tillage	0.103	0.117	0.017	0.033	1.17	1.89	13.2	9.94
SE P*Tillage	0.108	0.127	0.019	0.034	1.128	2.1	13.4	10.93

Concentration of Zn in canola seed and wheat grain was also reduced by P application at both sites (Tables B7 and B8). At the Research Centre, seed Zn concentration was higher under CT than NT when no P was applied, but similar under the two tillage systems when P was added (Table B7).

Cadmium concentration in canola seed was increased with P fertilization at the Research Centre Farm (Table B7) while concentration of Cd in wheat grain was increased with P fertilization at the MZTRA (Table B8).

B8: Wheat seed N, P, Zn and Cd as influenced by tillage system and P fertilization at two locations (combined for 1999 and 2000).

	Grain N (%)		Grain P (ppm)		Grain Zn (ppm)		Grain Cd (ppb)	
Phosphorus	Research Centre							
kg ha^{-1}	CT	NT	CT	NT	CT	NT	CT	NT
0	2.60	2.55	0.414	0.427	29.9	31.3	35.1	26.3
25	2.59	2.56	0.423	0.415	28.1	29.7	35.8	29.4
50	2.61	2.53	0.426	0.430	27.6	28.3	35.0	28.7
Mean	2.60	2.55	0.421	0.424	28.5	29.8	35.3	28.1

	MZTRA							
0	2.46	2.41	0.406	0.413	40.0	36.3	16.6	16.3
25	2.42	2.37	0.412	0.424	33.0	36.1	22.4	21.3
50	2.44	2.40	0.431	0.437	31.1	31.3	26.5	21.3
Mean	2.44	2.40	0.416	0.425	34.7	34.5	21.8	19.6
	Analysis of Variance							
	Research Centre	MZTRA	Research Centre	MZTRA	Research Centre	MZTRA	Research Centre	MZTRA
Phosphorus	0.03	1.86	2.11	13.07****	11.31****	6.94**	0.93	25.40****
Tillage	1.38	0.92	0.26	1.41	1.62	0.01	9.61*	1.73
P*Tillage	0.41	0.04	2.48	0.21	0.34	1.69	0.48	2.97
	P-values							
Low P vs No P	ns	0.0622	ns	0.0897	0.0032	0.0578	ns	0.0001
No P vs High P	ns	ns	ns	0.0001	0.0001	0.0003	ns	0.0001
Low P vs High P	ns	ns	0.0617	0.0014	ns	0.0746	ns	0.0604
	Standard Error Values							
SE P	0.100	0.176	0.009	0.013	0.599	1.31	5.47	2.02
SE Tillage	0.102	0.178	0.009	0.013	0.706	1.07	5.53	2.10
SE P*Tillage	0.104	0.178	0.01	0.014	0.848	1.86	5.65	2.28

2000 Flax - Effects of Preceding Crop, Residual P, Tillage and P in Flax
Biomass yield

Flax biomass yield was consistently higher when grown on wheat stubble than on canola stubble (Tables B5 and B6). Part of the effect of preceding crop may be due to the high density of volunteer canola in the flax during early growth, as early season weed competition is particularly damaging in flax. Biomass yield was not significantly influenced by tillage system at the Research Centre Farm, but was increased by NT as compared to CT at the MZTRA . The biomass yield increase due to NT was greater after canola than after wheat.

Phosphorus fertilization of the flax crop increased biomass yield under NT when grown on canola and under CT when grown on wheat at the Research Centre Farm. In contrast, on the MZTRA , application of P fertilizer to the flax decreased biomass yield with all crop-tillage system combinations. There was no influence from the residual effect of P applications in the preceding crops on biomass yield of flax at either location.

Table B5: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on flax biomass yield (kg ha^{-1}) at two locations (2000)

		Research Centre	MZTRA

		Canola			Wheat			Canola			Wheat		
P in 2000	P in 1999	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean
0	0	218	258	238	303	382	343	1015	1185	1100	1634	1685	1660
0	25	236	221	229	348	408	378	945	1309	1127	1555	1631	1593
0	50	232	219	226	359	364	362	929	1250	1090	1606	1750	1678
Mean of 0 P		229	233	231	337	385	361	963	1248	1106	1598	1689	1644
25	0	239	296	268	397	456	427	930	1041	986	1583	1670	1627
25	25	254	309	282	354	378	366	987	1083	1035	1716	1625	1671
25	50	188	261	225	401	340	371	874	1098	986	1330	1344	1337
Mean of 25 P		227	289	258	384	391	388	930	1074	1002	1543	1546	1545
Mean across P		228	261	244	360	388	374	947	1161	1054	1571	1618	1594

Seed Yield

Seed yield of flax was higher when grown after wheat than after canola at both locations under both tillage systems (Tables B6 and B7). This may reflect early season weed competition from the volunteer canola. However, preliminary examination of mycorrhizal infection indicates higher mycorrhizal formation after wheat than canola, which may have enhanced P nutrition and crop yield. Seed yield tended to be higher under NT than CT at the MZTRA location, but was not significantly influenced by tillage system at the Research Centre location.

Seed yield of flax was not increased by P application to the flax crop at either location. However, there was a tendency for seed yield to decrease with application of P to flax under NT at the Research Centre location. Flax does not tend to proliferate roots in fertilizer reaction zones and so is relatively ineffective at absorbing P from fertilizer applications. At the MZTRA location, P fertilization of the preceding crop led to higher flax seed yield the following year, with the effect being greater when wheat was the preceding crop as compared to canola. Increased residual P from previous fertilizer applications may be as or more available to flax than side-banded P applications.

Table B6: Statistical analysis using Proc Mixed for effects of phosphorus fertilizer and tillage system on seed and biomass yield of flax at two sites in 2000.

		Biomass Yield				Seed Yield			
Source	DF	Research Centre		MZTRA		Research Centre		MZTRA	
		P-value	SE	P-value	SE	P-value	SE	P-value	SE
P (Flax)	1	0.0728	12.1	0.0203	61.8	ns	28.3	ns	33.8
Preceding Crop	1	0.0001	12.1	0.0001	61.8	0.0016	28.8	0.0001	33.8
P (Flax)*Preceding Crop	1	ns	16.0	ns	68.7	ns	38.2	ns	40.5
P (Residual)	1	ns	14.2	ns	65.4	ns	33.4	0.0725	40.6

P (Residual)* P (Flax)	2	ns	19.1	ns	75.0	ns	45.3	ns	48.9
P (Residual) * Preceding Crop	2	ns	19.1	ns	75.0	ns	45.6	0.0574	48.9
P (Residual) * Preceding Crop * P (Flax)	2	ns	26.3	ns	91.3	ns	62.9	ns	62.4
Tillage	1	ns	13.6	0.0772	63.1	ns	30.8	0.0978	40.7
P(Flax) * Tillage	1	ns	17.1	ns	69.8	0.0819	39.7	ns	46.4
Preceding Crop * Tillage	1	ns	17.1	0.0524	69.8	ns	40.0	ns	46.4
Preceding Crop * P (Flax) * Tillage	1	0.0986	22.6	ns	81.8	ns	53.4	ns	56.1
P (Residual) * Tillage	2	ns	20.1	ns	76.1	ns	46.9	ns	53.9
P (Residual) * P (Flax) * Tillage	2	ns	27.0	ns	92.1	ns	63.8	ns	66.3
P (Residual) * Preceding Crop * Tillage	2	ns	27.0	ns	92.1	ns	64.1	ns	66.3
P (Residual) * Preceding Crop * P (Flax) *Tillage	2	ns	37.3	ns	117.9	ns	88.7	ns	85.9

Table B7: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on flax seed yield (kg/ha) at two locations (2000)

		Research Centre						MZTRA					
		Canola			Wheat			Canola			Wheat		
P in 2000	P in 1999	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean
0	0	1975	1909	1942	2066	2212	2139	2190	2362	2276	2378	2499	2439
0	25	1922	2066	1994	2151	2202	2177	2337	2466	2402	2397	2564	2481
0	50	1922	1910	1916	2102	2118	2110	2303	2487	2395	2622	2697	2660
Mean of 0 P		1940	1962	1951	2106	2177	2142	2277	2438	2358	2466	2587	2526
25	0	1961	1854	1908	1957	2032	1995	2236	2310	2273	2567	2598	2583
25	25	1886	1899	1893	2179	2176	2178	2309	2427	2368	2327	2592	2460
25	50	1982	1652	1817	2320	2202	2261	2428	2336	2382	2597	2686	2642
Mean of 25 P		1943	1802	1872	2152	2137	2144	2324	2358	2341	2497	2625	2561
Mean across P		1941	1882	1912	2129	2157	2143	2301	2398	2349	2481	2606	2544

Plant Diseases

Assessment was made in the flax for mildew, rust, pasmo on leaves, pasmo on stems, sclerotinia and lodging. There was no measurable mildew, rust or sclerotinia at either location and lodging was minimal and not affected y treatment.

Pasmo is a fungus disease of flax. Early infection with pasmo can reduce yield and quality of flax markedly, by causing early ripening and reduction of seed fill. Later infection may result in losses from breaking-off of diseased bolls. Pasmo shows up as brown spots on the leaves. Later in the season, as the plants begin to ripen, small brown spots may appear on infected stems, joining to form brown bands encircling the stems.

Table B8: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on leaf pasmo in flax at two locations (2000)

		Research Centre						MZTRA					
		Canola			Wheat			Canola			Wheat		
P in 2000	P in 1999	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean
0	0	5.75	7.00	6.38	8.00	8.00	8.00	5.75	6.50	6.13	7.75	8.00	7.88
0	25	6.00	7.00	6.50	7.75	8.00	7.88	6.50	7.25	6.88	7.75	7.75	7.75
0	50	6.75	6.75	6.75	7.50	7.50	7.50	6.00	6.75	6.38	7.75	8.25	8.00
Mean of 0 P		6.17	6.92	6.54	7.75	7.83	7.79	6.08	6.83	6.46	7.75	8.00	7.88
25	0	6.25	6.50	6.38	8.00	8.25	8.13	6.00	6.50	6.25	8.25	8.00	8.13
25	25	6.00	7.00	6.50	8.00	8.25	8.13	5.50	7.00	6.25	7.50	8.25	7.88
25	50	5.75	6.50	6.13	8.25	8.25	8.25	5.75	6.00	5.88	7.50	7.75	7.63
Mean of 25 P		6.00	6.67	6.33	8.08	8.25	8.17	5.75	6.50	6.13	7.75	8.00	7.88
Mean across P		6.09	6.80	6.44	7.92	8.04	7.98	5.92	6.67	6.29	7.75	8.00	7.88

Table B9: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on stem pasmo in flax at two locations (2000)

		Research Centre						MZTRA					
		Canola			Wheat			Canola			Wheat		
P in 2000	P in 1999	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean
0	0	3.75	6.00	4.88	5.75	6.25	6.00	4.75	6.25	5.50	7.00	8.00	7.50
0	25	4.25	5.50	4.88	5.25	6.50	5.88	6.00	6.75	6.38	7.25	7.75	7.50
0	50	5.00	6.25	5.63	4.75	6.00	5.38	5.25	6.25	5.75	6.75	7.75	7.25
Mean of 0 P		4.33	5.92	5.13	5.25	6.25	5.75	5.33	6.42	5.88	7.00	7.83	7.42
25	0	4.75	5.75	5.25	6.00	6.25	6.13	4.75	6.00	5.38	7.50	7.50	7.50
25	25	4.25	5.50	4.88	5.50	6.50	6.00	5.00	6.50	5.75	7.00	8.00	7.50
25	50	4.00	6.25	5.13	5.00	6.00	5.50	5.00	6.25	5.63	6.75	7.50	7.13
Mean of 25 P		4.33	5.83	5.08	5.50	6.25	5.88	4.92	6.25	5.58	7.08	7.67	7.38
Mean across P		4.33	5.88	5.10	5.38	6.25	5.81	5.13	6.34	5.73	7.04	7.75	7.40

Table B10: Statistical analysis using Proc Mixed for effects of phosphorus fertilizer and tillage system on Leaf and stem pasmo at two sites in 2000.

		Leaf Pasmo				Stem Pasmo			
Source	DF	Research Centre		MZTRA		Research Centre		MZTRA	
		P-value	SE	P-value	SE	P-value	SE	P-value	SE
P (Flax)	1	ns	0.28	ns	0.12	ns	0.22	ns	0.22
Preceding Crop	1	0.0001	0.24	0.0023	0.13	0.0164	0.22	0.0056	0.28
P (Flax)*Preceding Crop	1	0.0461	0.30	0.0923	0.16	ns	0.25	ns	0.29

P (Residual)	1	ns	0.25	ns	0.12	ns	0.25	0.0374	0.22
P (Residual)* P (Flax)	2	ns	0.32	0.0330	0.16	ns	0.28	ns	0.25
P (Residual) * Preceding Crop	2	ns	0.28	0.0541	0.16	0.0186	0.28	0.0658	0.30
P (Residual) * Preceding Crop * P (Flax)	2	ns	0.36	ns	0.21	ns	0.34	ns	0.33
Tillage	1	ns	0.26	0.0267	0.12	0.0158	0.27	0.0113	0.23
P(Flax) * Tillage	1	ns	0.31	ns	0.15	ns	0.29	ns	0.24
Preceding Crop * Tillage	1	0.0111	0.28	0.0128	0.15	0.0371	0.29	0.0379	0.30
Preceding Crop * P (Flax) * Tillage	1	ns	0.34	ns	0.19	ns	0.33	ns	0.32
P (Residual) * Tillage	2	ns	0.29	ns	0.15	ns	0.32	ns	0.25
P (Residual) * P (Flax) * Tillage	2	ns	0.37	0.0304	0.20	ns	0.38	ns	0.30
P (Residual) * Preceding Crop * Tillage	2	ns	0.34	ns	0.21	ns	0.38	ns	0.34
P (Residual) * Preceding Crop * P (Flax) *Tillage	2	ns	0.45	ns	0.27	ns	0.47	ns	0.40

Both leaf and stem pasmo ratings were higher in wheat than canola on both locations under both tillage systems (Tables B8-B10). Pasmo was generally higher under NT than CT and there was a strong tillage by preceding crop interaction with differences between wheat and canola being greater under CT than NT management.

Phosphorus application to the flax tended to decrease leaf pasmo in flax where canola was the preceding crop, but increased it at the Research Centre Farm and did not affect it at the MZTRA , where wheat was the preceding crop (Tables B8 and B10). At the MZTRA leaf pasmo also decreased with residual P application where P was applied to the flax crop, but not where the flax crop was not fertilized with P. This may relate to some incipient fertilizer damage caused to the flax by the side-banded P.

Where wheat was the preceding crop, there was a tendency for stem pasmo to decrease with increasing residual P, both at the MZTRA and the Research Centre Farm (Tables B9 and B10). Overall, at the MZTRA , stem pasmo decreased with residual P, but the effect was mainly where wheat was the preceding crop.

Pasmo severity was not consistently related to final seed yield. Seed yield of flax tended to be greater under NT than CT and after wheat rater than after canola. This is in opposition to the effects on yield noted. However, the decrease in pasmo with increasing residual P reflects the yield response.

Nutrient Content at Five Weeks and in the Seed

Tissue P: Phosphorus is needed by the crop early in the growing season to ensure optimum crop yield. Early season tissue P concentration was positively correlated with biomass yield at 5 weeks ($r=0.22$, $p<0.03$). Early-season P concentration in flax tissue was higher after wheat than canola at the Research Centre farm, but not at the MZTRA (Table B11 and B12). Biomass yield was also higher after wheat than canola (Table B5 and B6), so the difference in Tissue P concentration was not due to dilution effects. Tissue P concentration increased when P was side-banded at seeding with the flax at both locations. Phosphorus applied to the preceding crop also increased P concentration in the flax at both locations, with the effect being greater after wheat than canola at the MZTRA . Application of 25 kg N ha^{-1} in the preceding crop produced similar P concentration to application of 25 kg N ha^{-1}, side-banded with the flax at seeding.

At both sites, tissue P was higher under CT than NT after canola, but did not differ with tillage after wheat. At the MZTRA , P applied in the previous crop had a greater effect under NT than CT when the preceding crop, while the effect was greater under CT than NT when the preceding crop was canola.

Table B11: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on flax tissue P concentration at five weeks at two locations (2000)

		Research Centre						MZTRA					
		Canola			Wheat			Canola			Wheat		
P in 2000	P in 1999	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean
0	0	0.455	0.375	0.415	0.475	0.490	0.483	0.378	0.360	0.369	0.343	0.328	0.335
0	25	0.450	0.425	0.438	0.498	0.490	0.494	0.403	0.355	0.379	0.380	0.368	0.374
0	50	0.473	0.458	0.465	0.475	0.480	0.478	0.438	0.358	0.398	0.393	0.430	0.411
Mean of 0 P		0.459	0.419	0.439	0.483	0.487	0.485	0.406	0.358	0.382	0.372	0.375	0.373
25	0	0.445	0.448	0.446	0.500	0.475	0.488	0.410	0.358	0.384	0.373	0.360	0.366
25	25	0.480	0.460	0.470	0.515	0.505	0.510	0.393	0.370	0.381	0.393	0.385	0.389
25	50	0.500	0.455	0.478	0.533	0.535	0.534	0.463	0.375	0.419	0.418	0.433	0.425
Mean of 25 P		0.475	0.454	0.465	0.516	0.505	0.510	0.422	0.368	0.395	0.394	0.393	0.393
Mean across P		0.467	0.437	0.452	0.500	0.496	0.498	0.414	0.363	0.389	0.383	0.384	0.384

Table B12: Statistical analysis using Proc Mixed for effects of phosphorus fertilizer and tillage system on tissue P and tissue Cd at five weeks at two sites in 2000.

		Tissue P				Tissue Cd			
Source	DF	Research Centre		MZTRA		Research Centre		MZTRA	
		P-value	SE	P-value	SE	P-value	SE	P-value	SE
P (Flax)	1	0.0002	0.0069	0.0143	0.0070	ns	37.10	ns	26.20
Preceding Crop	1	0.0001	0.0069	ns	0.0070	0.0001	37.10	0.0001	26.20
P (Flax)*Preceding Crop	1	ns	0.0083	ns	0.0084	ns	38.70	ns	27.46

P (Residual)	1	0.0010	0.0076	0.0001	0.0077	ns	37.90	ns	26.84
P (Residual)* P (Flax)	2	ns	0.0095	ns	0.0096	0.0531	40.24	ns	28.67
P (Residual) * Preceding Crop	2	ns	0.0095	0.0756	0.0095	ns	40.24	ns	28.67
P (Residual) * Preceding Crop * P (Flax)	2	0.0664	0.0124	ns	0.0125	ns	44.52	ns	32.03
Tillage	1	0.0116	0.0069	0.0867	0.0087	ns	51.32	ns	34.04
P(Flax) * Tillage	1	ns	0.0083	ns	0.0099	ns	52.49	0.0934	35.03
Preceding Crop * Tillage	1	0.0411	0.0083	0.0002	0.0099	ns	53.63	ns	35.03
Preceding Crop * P (Flax) * Tillage	1	ns		ns	0.0119	ns	54.75	0.0487	36.92
P (Residual) * Tillage	2	ns	0.0095	ns	0.0109	ns	53.63	ns	35.99
P (Residual) * P (Flax) * Tillage	2	ns	0.0124	ns	0.0135	ns	54.75	ns	38.72
P (Residual) * Preceding Crop * Tillage	2	ns	0.0124	0.0103	0.0135	ns	56.91	ns	38.72
P (Residual) * Preceding Crop * P (Flax) *Tillage	2	0.0548	0.0167	ns	0.0176	0.0973	62.97	ns	43.67

Table B13: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on flax tissue Cd Concentration at five weeks at two locations (2000)

		Research Centre						MZTRA					
		Canola			Wheat			Canola			Wheat		
P in 2000	P in 1999	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean
0	0	743	772	757	603	650	627	551	430	491	436	388	412
0	25	803	770	787	702	672	687	560	376	468	483	400	442
0	50	662	813	737	693	681	687	558	460	509	450	388	419
Mean of 0 P		736	785	760	666	668	667	557	422	489	456	392	424
25	0	714	771	742	700	675	688	552	424	488	432	387	410
25	25	693	703	698	645	643	644	550	515	533	463	381	422
25	50	773	718	746	688	692	690	535	554	544	477	389	433
Mean of 25 P		727	731	729	678	670	674	546	498	522	457	386	422
Mean across P		732	758	745	672	669	671	552	460	506	457	389	423

Tissue Cd: Tissue Cd concentration at 5 weeks was higher when flax followed canola rather than wheat (Tables B12 and B13). This may relate to dilution/concentration effects, as flax biomass yield at 5 weeks was higher after wheat than canola. Effects of tillage system and P management were minor or nonsignificant.

Tissue Zn: Tissue concentration of Zn was lower when flax was grown after canola rather than wheat (Tables B14 and B15). Tissue Zn concentration also decreased when P was side-banded with the flax at seeding. On the MZTRA , P application in the preceding crop also led to lower tissue Zn concentrations. The reduction with residual P tended to be greater when canola rather than wheat was the preceding crop, particularly when no P was applied with the flax. At the Research Centre, tissue Zn concentration was higher under NT than CT, while differences were not significant at the MZTRA . The differences were not due to dilution, as biomass yield at 5 weeks was not reduced by NT at the Research Centre.

Table B14: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on flax tissue Zn concentration at five weeks at two locations (2000)

		Research Centre						MZTRA					
		Canola			Wheat			Canola			Wheat		
P in 2000	P in 1999	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean
0	0	19.5	20.6	20.1	24.0	21.6	22.8	22.4	23.1	22.8	20.1	22.2	21.1
0	25	18.3	21.3	19.8	19.7	24	21.9	18.5	20.0	19.3	20.0	22.6	21.3
0	50	17.6	20.1	18.8	18.6	21.1	19.8	17.3	17.4	17.4	19.0	21.8	20.4
Mean of 0 P		18.5	20.7	19.6	20.7	22.2	21.5	19.4	20.2	19.8	19.7	22.2	20.9
25	0	16.1	20.7	18.4	17.8	20.6	19.2	17.8	18.4	18.1	19.6	21.0	20.3
25	25	16.1	19.2	17.6	18.3	21.7	20.0	16.6	17.4	17.0	16.7	18.4	17.6
25	50	16.3	18.6	17.5	18.6	21.8	20.2	17.2	15.8	16.5	19.4	19.4	19.4
Mean of 25 P		16.2	19.5	17.8	18.2	21.4	19.8	17.2	17.2	17.2	18.6	19.6	19.1
Mean across P		17.4	20.1	18.7	19.5	21.8	20.6	18.3	18.7	18.5	19.2	20.9	20.0

Seed P: Concentration of P in the seed at the Research Centre was higher when flax followed wheat than when flax followed canola (Tables B15 and B16). This was not due to dilution, as flax seed yield was higher after wheat than canola. Concentration of P in the seed increased with side-banded application of P at both sites. Seed P also increased to a similar extent when P had been applied to the preceding crop. There was an interaction between preceding crop and tillage system, with higher seed P occurring under NT than CT in wheat at both locations. Seed P tended to be slightly higher under NT than CT at the Research Centre, but not at the MZTRA .

Table B15: Statistical analysis using Proc Mixed for effects of phosphorus fertilizer and tillage system on tissue Zn at five weeks and seed P at two sites in 2000.

		Tissue Zn				Seed P			
Source	DF	Research Centre		MZTRA		Research Centre		MZTRA	
		P-value	SE	P-value	SE	P-value	SE	P-value	SE
P (Flax)	1	0.0024	0.408	0.0001	1.143	0.0008	0.0157	0.0001	0.0034
Preceding Crop	1	0.0007	0.408	0.0034	1.143	0.0053	0.0160	ns	0.0034
P (Flax)*Preceding Crop	1	ns	0.562	ns	1.196	ns	0.0160	ns	0.0046
P (Residual)	1	ns	0.491	0.0017	1.170	0.0001	0.0160	0.0001	0.0041

P (Residual)* P (Flax)	2	ns	0.681	ns	1.247	ns	0.0170	ns	0.0056
P (Residual) * Preceding Crop	2	ns	0.681	0.0950	1.247	ns	0.0170	ns	0.0056
P (Residual) * Preceding Crop * P (Flax)	2	ns	0.954	0.0826	1.388	ns	0.0177	ns	0.0078
Tillage	1	0.0057	0.430	ns	1.561	0.0920	0.0177	ns	0.0036
P(Flax) * Tillage	1	ns	0.577	ns	1.600	ns	0.0180	ns	0.0048
Preceding Crop * Tillage	1	ns	0.577	ns	1.600	0.0100	0.0184	0.0342	0.0048
Preceding Crop * P (Flax) * Tillage	1	ns	0.794	ns	1.676	ns	0.0195	ns	0.0065
P (Residual) * Tillage	2	ns	0.694	ns	1.639	ns	0.0184	ns	0.0057
P (Residual) * P (Flax) * Tillage	2	ns	0.963	ns	1.749	ns		ns	0.0079
P (Residual) * Preceding Crop * Tillage	2	ns	0.963	ns	1.749	ns	0.0195	ns	0.0079
P (Residual) * Preceding Crop * P (Flax) *Tillage	2	ns	1.349	ns	1.950	0.0349	0.0215	ns	0.0110

Seed Cd: Concentration of Cd in flax seed was higher after canola than wheat at both locations (Tables B17 and B18). At the MZTRA , side-banded P increased seed Cd concentration, particularly under NT in canola, but there was no response at the Research Centre. At both locations, the P that was applied in the preceding crop increased seed Cd concentration, with the effect at the Research Centre being greater following canola than wheat. At the Research Centre, seed Cd tended to be higher under NT than CT when flax was grown after canola, but tillage had no effect when flax was grown after wheat.

Seed Zn: Flax seed Zn concentration was lower after canola than wheat at both locations (Tables B18 and B19). It was also reduced by side-banded P and by P application in the preceding crop at the MZTRA . The reduction with P application in the preceding crop tended to be greater when no P was applied to the flax and on average, tended to be higher in wheat than in canola.

At the Research Centre farm, Zn concentration in the seed was higher under NT than CT, with the effect of tillage being much greater in wheat than canola.

Table B16: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on flax seed P concentration at two locations (2000)

		Research Centre						MZTRA					
		Canola			Wheat			Canola			Wheat		
P in 2000	P in 1999	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean

0	0	0.485	0.533	0.509	0.508	0.553	0.530	0.438	0.423	0.430	0.435	0.433	0.434
0	25	0.520	0.528	0.524	0.503	0.58	0.541	0.455	0.458	0.456	0.443	0.465	0.454
0	50	0.545	0.558	0.551	0.540	0.603	0.571	0.47	0.473	0.471	0.468	0.498	0.483
Mean of 0 P		0.517	0.539	0.528	0.517	0.578	0.548	0.454	0.451	0.453	0.448	0.465	0.457
25	0	0.518	0.530	0.524	0.535	0.590	0.563	0.440	0.455	0.448	0.460	0.460	0.460
25	25	0.533	0.583	0.558	0.540	0.570	0.555	0.488	0.468	0.478	0.463	0.495	0.479
25	50	0.553	0.590	0.571	0.535	0.598	0.566	0.500	0.495	0.498	0.5	0.513	0.506
Mean of 25 P		0.534	0.568	0.551	0.537	0.586	0.561	0.476	0.473	0.474	0.474	0.489	0.482
Mean across P		0.526	0.554	0.540	0.527	0.582	0.555	0.465	0.462	0.464	0.461	0.477	0.469

Table B17: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on flax seed Cd Concentration at two locations (2000)

		Research Centre						MZTRA					
		Canola			Wheat			Canola			Wheat		
P in 2000	P in 1999	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean
0	0	282	296	289	257	262	259	243	214	229	201	202	202
0	25	330	341	336	243	270	256	267	221	244	208	205	206
0	50	300	377	338	290	277	284	259	267	263	207	199	203
Mean of 0 P		304	338	321	263	270	266	256	234	245	205	202	204
25	0	284	325	305	275	276	275	249	249	249	186	201	193
25	25	319	339	329	267	258	262	255	278	266	219	226	222
25	50	317	345	331	253	284	268	266	275	271	233	219	226
Mean of 25 P		307	337	322	265	273	269	257	267	262	213	215	214
Mean across P		306	338	322	264	272	268	257	251	254	209	209	209

Table B18: Statistical analysis using Proc Mixed for effects of phosphorus fertilizer and tillage system on seed Cd at five weeks and seed Zn at two sites in 2000.

		Seed Cd Concentration				Seed Zn Concentration			
Source	DF	Research Centre		MZTRA		Research Centre		MZTRA	
		P-value	SE	P-value	SE	P-value	SE	P-value	SE
P (Flax)	1	ns	8.96	0.0130	9.95	0.0912	1.14	0.0001	2.16
Preceding Crop	1	0.0001	8.96	0.0001	9.95	0.0002	1.14	0.0001	2.16

P (Flax)*Preceding Crop	1	ns	10.05	ns	10.62	ns	1.17	ns	2.19
P (Residual)	1	0.0149	9.52	0.0024	10.29	ns	1.15	0.0056	2.18
P (Residual)* P (Flax)	2	ns	11.03	ns	11.26	ns	1.19	0.0796	2.22
P (Residual) * Preceding Crop	2	0.0227	11.03	ns	11.26	ns	1.19	0.0658	2.22
P (Residual) * Preceding Crop * P (Flax)	2	ns	13.56	ns	12.98	ns	1.13	ns	2.31
Tillage	1	ns	11.83	ns	12.12	0.0191	1.31	ns	2.44
P(Flax) * Tillage	1	ns	12.67	0.0695	13.21	ns	1.34	ns	2.46
Preceding Crop * Tillage	1	0.0602	12.67	ns	12.68	0.0006	1.39	ns	2.46
Preceding Crop * P (Flax) * Tillage	1	ns	12.67	ns	12.68	ns	1.39	ns	2.52
P (Residual) * Tillage	2	ns	13.46	ns	13.21	ns	1.36	ns	2.49
P (Residual) * P (Flax) * Tillage	2	ns	15.60	ns	14.71	ns	1.43	ns	2.57
P (Residual) * Preceding Crop * Tillage	2	ns	15.60	ns	13.73	ns	1.43	ns	2.57
P (Residual) * Preceding Crop * P (Flax) *Tillage	2	0.0600	19.17	ns	17.31	ns	1.56	ns	2.27

Table B19: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on flaxseed Zn Concentration at two locations (2000)

		Research Centre						MZTRA					
		Canola			Wheat			Canola			Wheat		
P in 2000	P in 1999	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean
0	0	27.2	33.0	30.1	27.1	34.8	31.0	31.1	32.4	31.8	31.3	35.5	33.4
0	25	28.7	31.9	30.3	27.1	35.1	31.1	30.0	32.6	31.3	31.3	31.5	31.4
0	50	26.3	30.7	28.5	26.5	34.7	30.6	25.8	29.3	27.6	31.0	32.5	31.8
Mean of 0 P		27.4	31.9	29.6	26.9	34.9	30.9	29.0	31.5	30.2	31.2	33.2	32.2
25	0	27.2	31.8	29.5	27.0	34.9	31.0	27.2	28.6	27.9	30.1	33.5	31.8
25	25	28.7	30.9	29.8	25.5	33.9	29.7	27.2	27.4	27.3	26.5	30.3	28.4
25	50	26.3	32.0	29.1	27.9	33.4	30.6	27.0	28.3	27.6	29.3	31.1	30.2
Mean of 25 P		27.4	31.6	29.5	26.8	34.1	30.4	27.1	28.1	27.6	28.6	31.6	30.1
Mean across P		27.4	31.7	29.6	26.9	34.5	30.7	28.1	29.8	28.9	29.9	32.4	31.2

2001 Results - Flax

The 2001 growing season was very wet from May through July, leading to difficulty with spraying and high disease pressure. There was very little rainfall in August.

Stand Density

Stand density was measured in the flax crop (Tables C1 and C2). Stand was higher after wheat than canola at both locations. Other effects on stand density were smaller and less consistent. Stand density tended to be reduced with side-banded MAP fertilizer on the Research Centre farm, except when following CT wheat and on the MZTRA after CT but not after NT. Stand density tended to increase with residual P after canola under NT at the Research Centre

Farm. There was a tendency for stand density to decline with residual P after wheat at the MZTRA.

Table C1: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on flax stand density (plants m^2) at two locations (2001)

		Research Centre						MZTRA					
		Canola			Wheat			Canola			Wheat		
P in 2001	P in 2000	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean
0	0	298	256	277	312	365	338	268	213	240	306	300	303
0	25	251	330	290	274	346	310	223	264	244	281	253	267
0	50	293	298	295	272	303	288	209	243	226	269	258	263
Mean of 0 P		280	295	287	286	338	312	234	240	237	285	270	278
25	0	290	257	273	316	296	306	208	254	231	241	294	268
25	25	266	306	286	323	275	299	251	263	257	246	224	235
25	50	229	294	261	314	304	309	229	234	231	230	283	256
Mean of 25 P		261	286	274	318	292	305	229	250	240	239	267	253
Mean across P		271	290	280	302	315	308	231	245	238	262	269	265

Biomass at Five Weeks

Early season flax growth was greater after wheat than canola at both sites (Tables C2 and C3). There was a tendency towards higher biomass yield with P application to the flax at the Research Centre after wheat, but not after canola. In contrast, at the MZTRA, biomass yield tended to decrease slightly with residual P after canola, particularly where P had been applied to the flax. There was also a tendency for higher biomass yield at the Research Centre farm with residual P, particularly after canola where no P was applied to the flax.

Flax biomass yield was higher under NT than CT at both sites. At the Research Centre, the difference between NT and CT was higher after canola than wheat. There was also higher response to P application to the flax under CT after wheat than in other tillage-crop combinations.

Table C2: Statistical analysis using Proc Mixed for effects of phosphorus fertilizer and tillage system on stand and biomass yield at five weeks at five weeks at two sites in 2001.

		Stand				Biomass at Five Weeks			
Source	DF	Research Centre		MZTRA		Research Centre		MZTRA	
		P-value	SE	P-value	SE	P-value	SE	P-value	SE
P (Flax)	1	ns	8.38	ns	7.75	ns	11.23	ns	25.43
Preceding Crop	1	0.0036	8.38	0.0021	7.75	0.0004	11.23	0.0001	25.43
P (Flax)*Preceding Crop	1	ns	10.62	ns	9.80	0.0762	13.43	ns	30.03

P (Residual)	2	ns	9.56	ns	8.83	ns	12.38	ns	27.82
P (Residual)* P (Flax)	2	ns	12.45	ns	11.49	ns	15.31	ns	34.01
P (Residual) * Preceding Crop	2	ns	12.45	0.0639	11.49	0.0417	15.31	0.0700	34.01
P (Residual) * Preceding Crop * P (Flax)	2	ns	16.80	ns	15.48	ns	19.92	ns	43.83
Tillage	1	ns	8.46	ns	7.86	0.0263	14.07	0.0398	32.22
P(Flax) * Tillage	1	0.0697	10.68	0.0890	9.89	ns	15.88	ns	35.96
Preceding Crop * Tillage	1	ns	10.68	ns	9.89	0.0034	15.88	ns	35.96
Preceding Crop * P (Flax) * Tillage	1	0.0205	14.10	ns	13.02	0.0863	18.99	ns	42.46
P (Residual) * Tillage	2	0.0097	12.51	ns	11.56	ns	17.50	ns	39.35
P (Residual) * P (Flax) * Tillage	2	ns	16.84	0.0831	15.54	ns	21.65	ns	48.10
P (Residual) * Preceding Crop * Tillage	2	ns	16.84	ns	15.54	0.0763	21.65	ns	48.10
P (Residual) * Preceding Crop * P (Flax) *Tillage	2	ns	23.20	ns	21.38	ns	28.18	ns	61.99

Table C3: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on flax biomass yield at five weeks (kg ha^{-1}) at two locations (2001)

		Research Centre						MZTRA					
		Canola			Wheat			Canola			Wheat		
P in 2001	P in 2000	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean
0	0	118	183	150	169	210	189	298	376	337	410	475	443
0	25	124	224	174	142	171	156	304	464	384	450	444	447
0	50	134	211	173	166	256	211	236	411	323	391	492	442
Mean of 0 P		125	206	166	159	212	186	279	417	348	417	470	444
25	0	124	176	150	231	214	223	289	514	402	426	587	506
25	25	108	262	185	221	188	204	339	489	414	413	415	414
25	50	101	193	147	203	252	228	261	401	331	440	618	529
Mean of 25 P		111	210	161	218	218	218	296	468	382	426	540	483
Mean across P		118	208	163	188	215	202	288	443	365	422	505	463

Table C4: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on seed yield (kg ha^{-1}) at two locations (2001)

		Research Centre						MZTRA					
		Canola			Wheat			Canola			Wheat		
P in 2001	P in 200	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean
0	0	1600	1591	1595	1577	1643	1610	1878	1732	1805	1956	1877	1917
0	25	1386	1734	1560	1714	1531	1622	1836	1640	1738	1960	1998	1979
0	50	1667	1556	1611	1497	1669	1583	1898	1619	1759	1770	1879	1825
Mean of 0 P		1551	1627	1589	1596	1615	1605	1871	1664	1767	1895	1918	1907
25	0	1428	1671	1550	1615	1692	1653	1909	1758	1834	1884	2066	1988

25	25	1455	1721	1588	1780	1686	1733	1806	1839	1823	2015	1617	1816
25	50	1491	1626	1558	1662	1703	1683	1730	1503	1617	1997	1897	1947
Mean of 25 P		1458	1673	1565	1686	1694	1690	1815	1700	1758	1974	1860	1917
Mean across P		1504	1650	1577	1641	1654	1648	1843	1682	1762	1935	1889	1910

Table C5: Statistical analysis using Proc Mixed for effects of phosphorus fertilizer and tillage system on seed and straw yield at two sites in 2001.

		Seed Yield				Straw Yield			
Source	DF	Research Centre		MZTRA		Research Centre		MZTRA	
		P-value	SE	P-value	SE	P-value	SE	P-value	SE
P (Flax)	1	ns	61.34	ns	68.5	0.0949	108.3	0.0088	131.24
Preceding Crop	1	0.0260	61.32	0.0008	68.5	ns	108.3	ns	131.40
P (Flax)*Preceding Crop	1	0.0777	66.07	ns	74.4	ns	118.2	ns	142.59
P (Residual)	2	ns	63.33	n	71.6	ns	113.4	ns	137.04
P (Residual)* P (Flax)	2	ns	69.75	ns	80.3	ns	127.3	ns	153.10
P (Residual) * Preceding Crop	2	ns	70.86	ns	80.3	ns	127.3	ns	153.10
P (Residual) * Preceding Crop * P (Flax)	2	ns	81.08	0.0512	95.4	ns	151.4	ns	181.01
Tillage	1	ns	78.10	ns	86.1	ns	129.4	0.0001	134.24
P(Flax) * Tillage	1	ns	81.34	ns	91.0	ns	137.8	0.0088	142.59
Preceding Crop * Tillage	1	0.0353	81.77	ns	91.0	ns	137.8	ns	142.59
Preceding Crop * P (Flax) * Tillage	1	ns	88.07	ns	100.3	ns	153.1	ns	162.94
P (Residual) * Tillage	2	ns	84.77	ns	95.8	ns	145.7	ns	153.10
P (Residual) * P (Flax) * Tillage	2	ns	94.31	ns	108.7	ns	167.1	ns	181.01
P (Residual) * Preceding Crop * Tillage	2	0.0103	94.31	ns	108.7	ns	167.1	0.0290	181.01
P (Residual) * Preceding Crop * P (Flax) *Tillage	2	ns	110.97	0.0840	130.8	ns	203.3	ns	226.74

Seed Yield

Seed yield at both locations was higher after wheat than canola, with the difference being greater under CT than NT at the Research Centre farm (Table C4 and C5). At the MZTRA , there was no benefit from either residual P or P side-banded with the flax and there was a tendency for seed yield to decline with residual P after canola, when P was side-banded with the flax. At the Research Centre farm, application of side-banded P fertilizer with flax tended to increase seed yield slightly after wheat, but decrease seed yield after canola, when the canola was CT. At the Research Centre farm, residual P did not benefit seed yield after wheat and but tended to increase seed yield after CT canola.

Tillage system did not influence flax yield in 2001.

Straw Yield and Harvest Index

Straw yield was not significantly influenced by tillage, preceding crop or P management at the Research Centre Farm (Table C5 and C6). There was a tendency ($p<0.0949$) for straw yield to increase with application of side-banded P fertilizer to the flax. At the MZTRA , straw yield was increased by application of side-banded P with the flax under CT, but not under NT. Straw yield was lower under NT than CT at the MZTRA . When canola was the preceding crop, straw yield tended to increase with residual P under CT, but decrease with residual P under NT.

Harvest index tended to be higher when flax followed wheat rather than canola (Table 7 and 8). Harvest index also tended to fall with application of side-banded P fertilizer when canola was the preceding crop. Harvest index at the Research Centre farm was higher when flax was grown under NT rather than CT.

Table C6: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on straw yield (kg ha^{-1}) at two locations (2001)

		Research Centre						MZTRA					
		Canola			Wheat			Canola			Wheat		
P in 2001	P in 2000	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean
0	0	2545	2275	2410	2385	2425	2405	3015	2915	2965	3255	2965	3110
0	25	2405	2545	2475	2595	2290	2443	3035	2750	2893	3020	2885	2953
0	50	2675	2235	2455	2695	2320	2508	3420	2530	2975	3240	2995	3118
Mean of 0 P		2542	2352	2447	2558	2345	2452	3157	2732	2944	3172	2948	3060
25	0	2675	2570	2623	2590	2260	2425	3485	2805	3145	3700	3160	3430
25	25	2360	2410	2385	2880	2585	2733	3655	3055	3355	3610	2630	3120
25	50	2675	2720	2698	2615	2410	2513	3760	2395	3078	3325	2995	3160
Mean of 25 P		2570	2567	2568	2695	2418	2557	3633	2752	3193	3545	2928	3237
Mean across P		2556	2459	2508	2627	2382	2504	3395	2742	3068	3358	2938	3148

Table C7: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on flax harvest index at two locations (2001)

		Research Centre						MZTRA					
		Canola			Wheat			Canola			Wheat		
P in 2001	P in 2000	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean
0	0	0.387	0.410	0.399	0.399	0.405	0.402	0.386	0.372	0.379	0.374	0.389	0.382
0	25	0.393	0.405	0.399	0.397	0.402	0.400	0.377	0.387	0.382	0.394	0.410	0.402
0	50	0.382	0.412	0.397	0.357	0.419	0.388	0.356	0.393	0.375	0.359	0.389	0.374
Mean of 0 P		0.387	0.409	0.398	0.385	0.409	0.397	0.373	0.384	0.379	0.376	0.396	0.386
25	0	0.343	0.400	0.372	0.383	0.428	0.406	0.354	0.386	0.370	0.335	0.397	0.366
25	25	0.379	0.417	0.398	0.382	0.401	0.391	0.326	0.376	0.351	0.357	0.381	0.369
25	50	0.341	0.374	0.357	0.390	0.415	0.403	0.313	0.389	0.351	0.376	0.387	0.382

Mean of 25 P	0.354	0.397	0.376	0.385	0.415	0.400	0.331	0.384	0.357	0.356	0.388	0.372
Mean across P	0.371	0.403	0.387	0.385	0.412	0.398	0.352	0.384	0.368	0.366	0.392	0.379

Table C8: Statistical analysis using Proc Mixed for effects of phosphorus fertilizer and tillage system on harvest index at two sites in 2001.

		Harvest index			
Source	DF	Research Centre		MZTRA	
		P-value	SE	P-value	SE
P (Flax)	1	ns	0.0048	0.0181	0.0088
Preceding Crop	1	0.0891	0.0048	ns	0.0088
P (Flax)*Preceding Crop	1	0.0545	0.0067	ns	0.0102
P (Residual)	2	ns	0.0057	ns	0.0095
P (Residual)* P (Flax)	2	ns	0.0080	ns	0.0114
P (Residual) * Preceding Crop	2	ns	0.0084	ns	0.0114
P (Residual) * Preceding Crop * P (Flax)	2	ns	0.0114	ns	0.0144
Tillage	1	0.0001	0.0048	ns	0.0114
P(Flax) * Tillage	1	ns	0.0069	0.0658	0.0125
Preceding Crop * Tillage	1	ns	0.0067	ns	0.0125
Preceding Crop * P (Flax) * Tillage	1	ns	0.0093	ns	0.0144
P (Residual) * Tillage	2	ns	0.0080	ns	0.0135
P (Residual) * P (Flax) * Tillage	2	ns	0.0114	ns	0.0161
P (Residual) * Preceding Crop * Tillage	2	ns	0.0114	ns	0.0131
P (Residual) * Preceding Crop * P (Flax) *Tillage	2	ns	0.0161	ns	0.0203

Mycorrhizal Association
Mycorrhizal association was measured on the roots of ten plants at five weeks of growth (Table C9). Mycorrhizal association was much greater at the Research Centre farm than at the MZTRA . Association at both locations was greater when the flax followed wheat than when it followed canola, although the difference was greater at the Research Centre farm than at the MZTRA (Figures 1 and 2). Association also tended to follow the same general patters as biomass yield. Interestingly, there was a tendency ($p<0.06$) for mycorrhizal association to increase with residual P at the Research Centre farm and decrease with residual P at the MZTRA (Table C9).

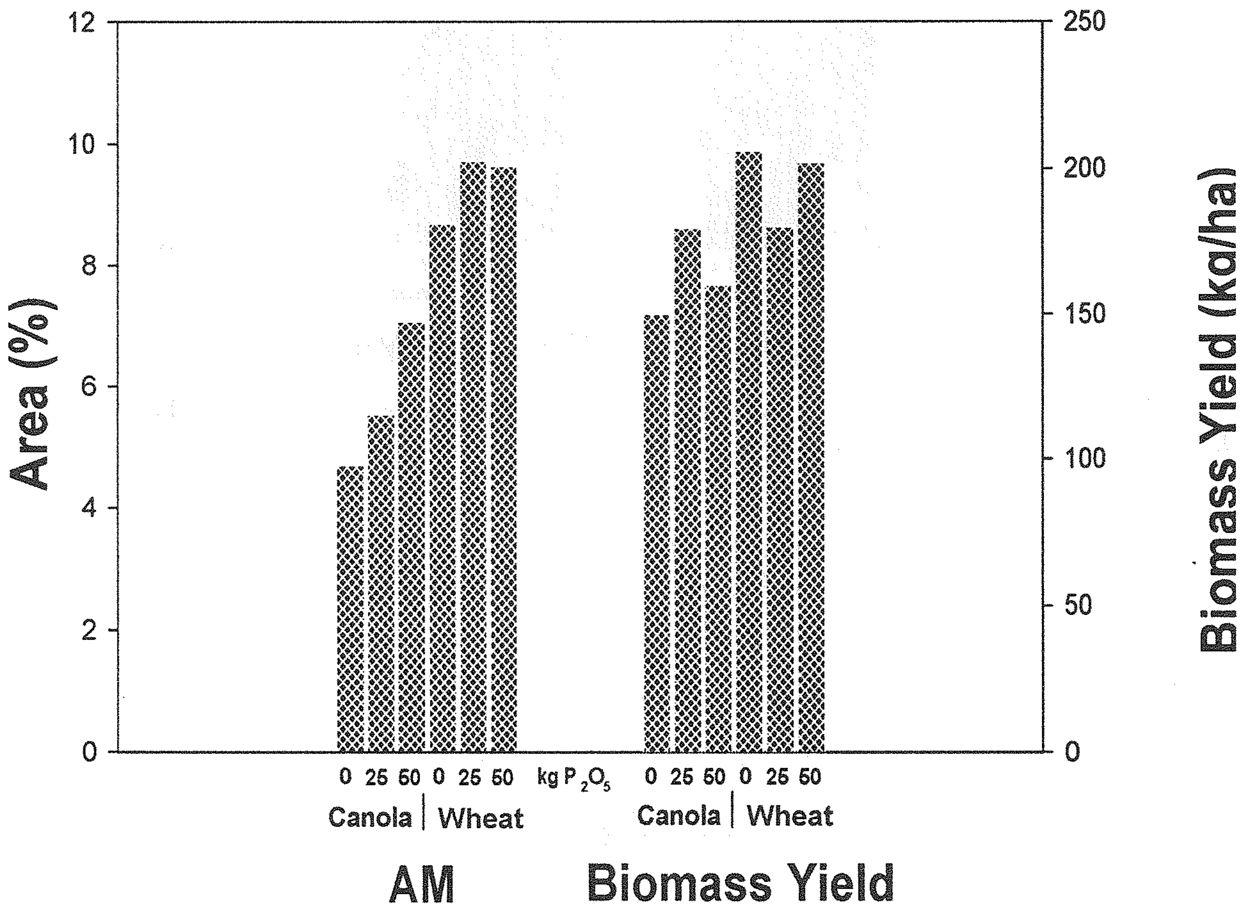

Figure 1: Effect of preceding crop and tillage system on mycorrhizal association and biomass yield at five weeks in 2001 at the Research Centre Farm.

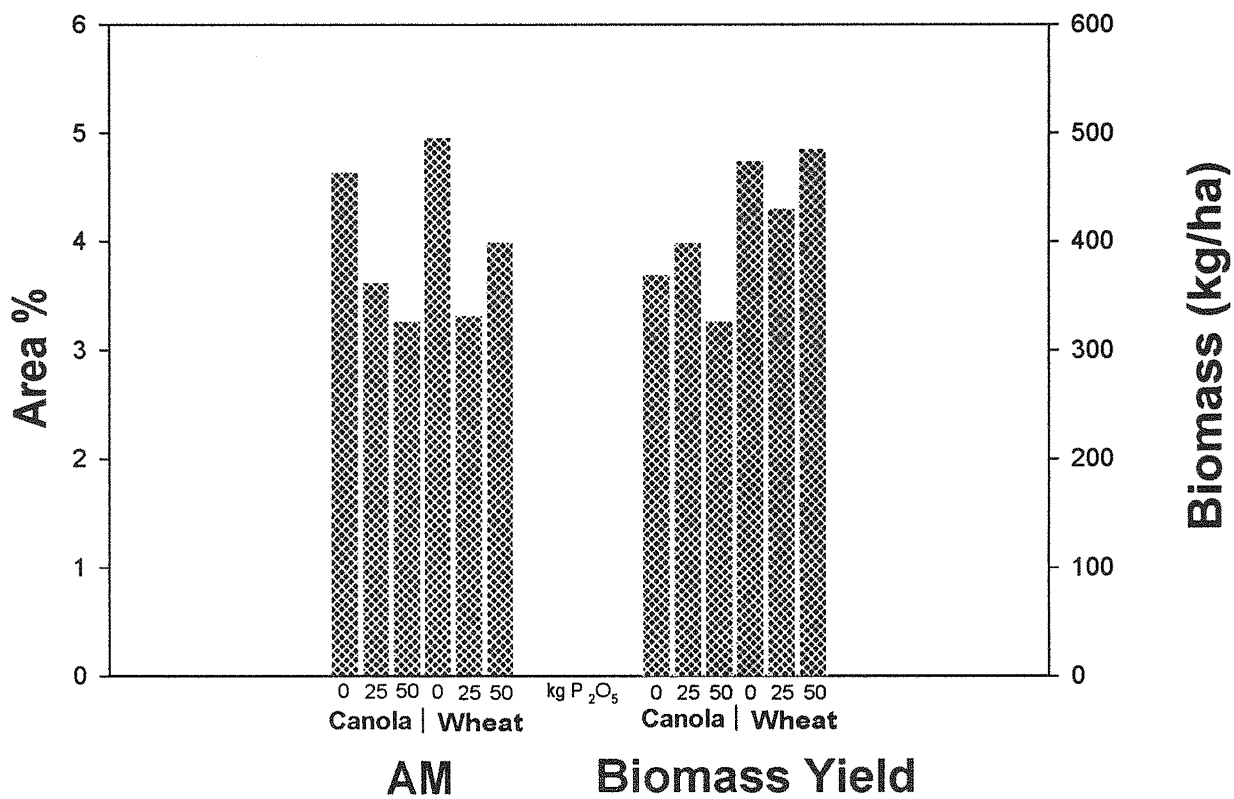

Figure 2: Effect of preceding crop and tillage system on mycorrhizal association and biomass yield at five weeks in 2001 at MZTRA.

Table C9: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on mycorrhiza incidence (% of root area covered) at two locations (2001)

		Research Centre						MZTRA					
		Canola			Wheat			Canola			Wheat		
P in 2001	P in 2000	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean	CT	NT	Mean
0	0	4.65	5.80	5.23	9.40	8.00	8.70	3.01	6.13	4.57	3.86	8.23	6.05
0	25	4.00	6.85	5.43	9.31	9.68	9.50	3.19	5.47	4.33	3.42	4.01	3.72
0	50	5.65	11.43	8.54	11.38	10.63	11.01	3.25	3.50	3.38	2.33	7.79	5.06
Mean of 0 P		4.77	8.03	6.40	10.03	9.44	9.73	3.15	5.03	4.09	3.20	6.68	4.94
25	0	3.83	4.52	4.18	11.04	6.33	8.69	5.14	4.30	4.72	2.12	5.64	3.88
25	25	5.41	5.85	5.63	7.19	12.68	9.94	3.17	2.70	2.94	1.52	4.33	2.93
25	50	6.40	4.84	5.62	8.10	8.46	8.28	1.90	4.42	3.16	2.18	3.69	2.94
Mean of 25 P		5.21	5.07	5.14	8.78	9.16	8.97	3.40	3.81	3.61	1.94	4.55	3.25
Mean across P		4.99	6.55	5.77	9.40	9.30	9.35	3.28	4.42	3.85	2.57	5.62	4.09

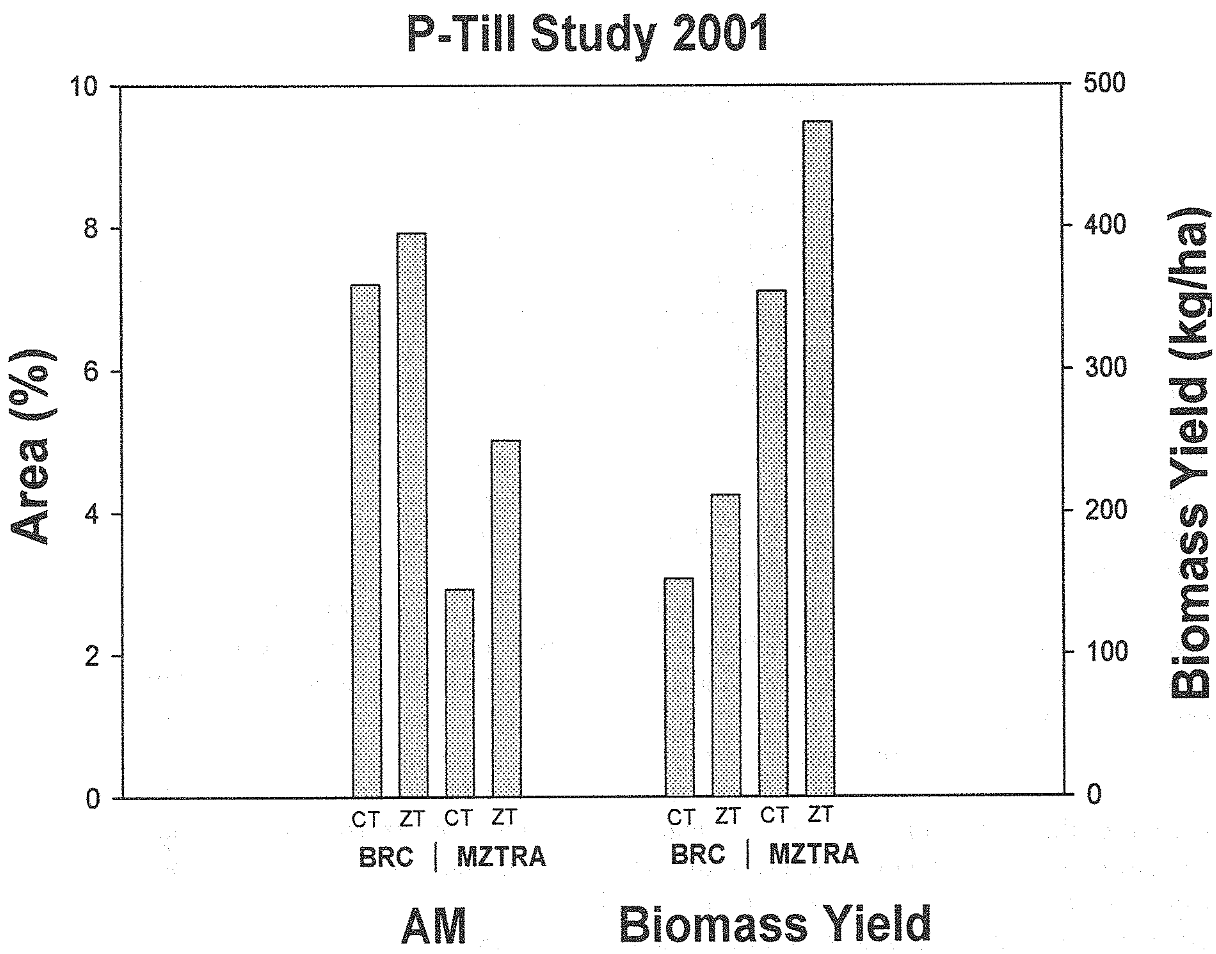

Figure 3: Mycorrhizal association and biomass yield at five weeks as affected by tillage system and location in 2001.

Association was reduced at both locations by side-banded P fertilization in the flax (Table C9). Association was greater with NT than CT at the MZTRA after both crops and at the Research Centre after canola (Figure 3). There was no effect of tillage system at the Research Centre after wheat. Level of mycorrhizal association was very high after wheat at the Research Centre farm, so it is possible that the tillage system had no effect due to the high degree of association present. Biomass yield and mycorrhizal association at five weeks tended to follow the same patterns of response to tillage management (Figure 3).

SUMMARY

In 1999, seed yield of wheat an canola was similar under CT and NT; where differences exited, seed yield was higher under NT. In contrast, in 2000, seed yield was consistently higher under CT than NT. Differences may be due to delayed seeding in 1999 and cold, wet conditions throughout 2000. Reduced aeration under NT in 2000 may have reduced crop yield. There was no P by tillage interaction in either year, indicating that P response was similar under the two tillage systems. Seed yield information for canola and wheat in 2001 is not available yet.

In 2000, early-season P and Zn concentration in flax tissue was higher after wheat than canola at the Research Centre farm, but not at the MZTRA . Biomass yield was also higher after wheat than canola, so the difference in tissue nutrient concentration was not due to dilution effects. Tissue P concentration increased and Zn decreased when P was side-banded at seeding with the flax. Phosphorus applied to the preceding crop also increased P and decreased Zn concentration in the flax. Applying 25 kg N ha^{-1} in the preceding crop produced similar P concentration to 25 kg N ha^{-1}, side-banded with the flax at seeding. Information on tissue nutrient concentration in 2001 is not available yet.

At both sites, tissue P was higher under CT than NT after canola, but did not differ with tillage after wheat. At the MZTRA , P applied in the previous crop had a greater effect under NT than CT when the preceding crop was wheat, while the effect was greater under CT than NT when the preceding crop was canola. At the Research Centre, tissue Zn concentration was lower under CT than NT, while differences were not significant at the MZTRA .

In 2001, mycorrhizal association in flax at five weeks was higher when the flax was grown after the mycorrhizal crop, wheat, than after the non-mycorrhizal crop, canola. Association was also generally increased by using reduced tillage as compared to conventional tillage. Mycorrhizal association and biomass yield at five weeks tended to respond similarly to preceding crop and tillage system at both locations. Increasing residual P tended to decrease association at the MZTRA but actually increased association slightly at the Research Centre Farm. However, application of P side-banded with the flax decreased mycorrrhizal association at both locations. Measurements of mycorrhizal association from 2000 has not been completed yet, due to difficulties with the root washing system which led to root damage.

Flax seed yield was similar under NT a dCT in both years. Seed yield of flax was higher when grown after wheat than after canola at both locations under both tillage systems in both years. This may reflect early season weed competition from the volunteer canola. However, mycorrhizal effects may also have played a role

Phosphorus applications had little impact on final flax yield. Seed yield tended to decrease with application of P to flax under NT at the Research Centre location in 2000, possibly due to seeding damage. At the Research Centre farm in 2001, seed yield of flax grown after wheat was increased slightly when P was side-banded with the flax but decreased with side-banded P in the flax grown after canola. Generally, side-banded P had little benefit for flaxseed production under the conditions of this experiment.

The effects of residual P on seed yield were not consistent. In 2000, at the MZTRA , P fertilization of the preceding crop led to higher flax seed yield the following year, with the effect

being greater when wheat was the preceding crop as compared to canola. In 2001, residual P did not increase flax seed yield.

In 2000, concentration of Cd in flax seed was higher after canola than wheat and was increased by application of P to the previous crop. At the MZTRA , side-banded P increased seed Cd concentration, particularly under NT in canola, but there was no response at the Research Centre. Tillage system did not consistently influence Cd concentration in the seed. Part of the effects on Cd concentration in the seed may relate to dilution/concentration changes, so it is important to evaluate the multi-year results to determine if effects are consistent. The analysis for 2001 is not complete yet.

Based on the interim information from this study, it appears that P nutrition of flax can be influenced by tillage system, preceding crop, residual P from fertilization of preceding crops and by side-banded P application in the flax. Therefore, it may be possible to select different P management strategies to optimize flax P nutrition and seed yield, depending on the cropping system and crop rotation used and the equipment available. Generally, production of flax after canola appears to be a poor option, possibly because of the effect on mycorrhizal association and P nutrition. However, the impact of extremely competitive volunteer canola competing with flax in the early stages of crop growth may also be important.

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