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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 µg 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 2: 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		No-till Farm		Research Centre		No-till Farm	
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 3: 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		No-till Farm		Research Centre		No-till Farm	
		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 no-till farm. 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 no-till farm 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 4: Effect of P application and tillage system on grain (kg/ha) for canola and wheat at two locations (1999)

	Canola				Wheat			
	Research Centre		No-till Farm		Research Centre		No-till Farm	

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 4 and 5), but was increased by P application on the no-till farm site. Canola seed yield also tended to be higher with NT than CT at the no-till farm 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 no-till farm, there was no significant effect of either P or tillage on wheat grain yield.

Table 5: 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		No-till Farm		Research Centre		No-till Farm	
		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 6 and 7). 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 No-till Farm, 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 No-till farm, where biomass yield increased with P application to a greater extent under CT than under NT.

Table 6: 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		No-till Farm		Research Centre		No-till Farm	
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 7: 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		No-till Farm		Research Centre		No-till Farm	
		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 No-Till Farm. Seed yield was also increased with P fertilization on the No-Till Farm, 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 8: Effect of P application and tillage system on grain (kg/ha) for canola and wheat at two locations (2000)

	Canola				Wheat			
	Research Centre		No-till Farm		Research Centre		No-till Farm	
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	1814	1034	1764	1410	4078	3210	4607	4126
Mean	1862	1071	1644	1329	4070	3025	4312	3995

Table 9: 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		No-till Farm		Research Centre		No-till Farm	
		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

2000 Flax - Residual Effects

Biomass yield

Flax biomass yield was consistently higher when grown on wheat stubble than on canola stubble (Tables 10 and 11). 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 No-till Farm. 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 No-till Farm, 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 10: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on flax biomass yield (g per 2 meters) at two locations (2000)

		Research Centre						No-till Farm					
		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	985.5	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 11 and 12). 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 No-Till Farm 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 No-Till Farm 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 11: 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		No-till Farm		Research Centre		No-till Farm	
		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 12: 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						No-till Farm					
		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 13: 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						No-till Farm					
		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 14: 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						No-till Farm					
		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 15: Statistical analysis using Proc Mixed for effects of phosphorus fertilizer and tillage system on Leaf and stem pasmo at two sites in 1999.

		Leaf Pasmo				Stem Pasmo			
Source	DF	Research Centre		No-till Farm		Research Centre		No-till Farm	
		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 13-15). 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 No-till Farm, where wheat was the preceding crop (Tables 13 and 15). At the No-till Farm 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 No-till Farm and the Research Centre Farm (Tables 14 and 15). Overall, at the No-till Farm, 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.

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.

Flax yield in 2000 was generally similar under NT and CT. Where differences existed, yield was higher under NT. The flax site was on a well-drained upper slope position which may have enhanced aeration. Seed yield of flax was higher when grown after wheat than after canola at both locations under both tillage systems This may reflect early season weed competition from the volunteer canola. However, mycorrhizal effects may also have played a role. Samples hae been taken for measurement of mycorrhizal colonization, but information is not available yet.

Seed yield of flax was not influenced 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. At the No-Till Farm 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. It may be a useful strategy for producers to increase P application in preceding crops, rather than fertilizer the flax crop, in order to increase P availability while eliminating the risk of seedling damage.

Information on P uptake at 5 weeks, mycorrhizal colonization, disease incidence in wheat and canola, and flax seed quality is in preparation.

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Proposal for Extension of Project

As significant plant responses occurred in the flax from residual applications of P fertilizer, it would be of interest to continue the cropping sequence and fertilizer management for an additional year, to determine the persistence of effects of P fertilization on following crops. As Cd concentration is a particular concern in durum wheat, I would like to propose seeding durum wheat on the flax stubble. The durum would either receive 0 or 25 kg P_20_5 per hectare, as the preceding flax received. This would allow us to determine the carry-over effect of P applied to the wheat or canola on the durum wheat crop two years after P application, as compared to a cropping system that had received P each year. Tissue would be analysed for P and Zn uptake and seed for N, P, Cd and a range of micronutrients. Mycorrhizal activity would also be assessed in selected plots. This would involve an additional 96 plots per year.

Objectives of project extension:
1) To determine the persistence of residual benefits of moderate rates of P fertilizer
2) To determine the benefit of annual applications of P fertilizer
3) To determine the impact of tillage system on P response and persistence of residual benefits
4) To determine the effect of applications of P fertilizer on Cd concentration in durum wheat
5) To determine the effect of P fertilizer management, tillage system and cropping sequence on grain quality and nutrient removal in durum wheat.
6) To determine the impact of tillage and P management on mycorrhizal activity in durum wheat

The additional budget for the expansion, above and beyond the previous budget would be:

Item	2001	2002	2003	Sum
Salary	$ 2,500.00	$ 2,500.00	$5,000.00	$ 10,000.00
Travel	$ 100.00	$ 100.00	$ 500.00	$ 700.00
Rentals	$ 400.00	$ 400.00	$ 400.00	$ 1,200.00
Contracts	$ 2,000.00	$ 2,000.00	$ 2,000.00	$ 6,000.00
Materials and Supplies	$ 5,000.00	$ 5,000.00	$ 5,000.00	$ 15,000.00
Equipment	$ 100.00	$ 100.00	$ 100.00	$ 300.00
Subtotal	$ 10,100.00	$ 10,100.00	$ 13,000.00	$ 33,200.00
Admin Services	$ 919.10	$ 919.10	$ 1,183.00	$ 3,021.20
Total	$ 11,019.10	$ 11,019.10	$ 14,183.00	$ 36,221.20

Costs are increased in 2003 because the durum wheat will be the only plots being run, so fixed costs will not be shared with the other crops.