# THE ROLE OF P FERTILITY AND MYCORRHIZAE IN FLAX PRODUCTION

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## ABSTRACT

Ensuring adequate P nutrition in flax is difficult, because flax is sensitive to seed-placed P and may be less efficient than many crops at using fertilizer P. Studies conducted for three years at two locations in western Manitoba indicated that flax seed yield, mycorrhizal association and Cd concentration were primarily influenced by preceding crop. Early-season P nutrition was enhanced by residual P and by side-banded P fertilizer, but effects on final seed yield were small. Reduced tillage decreased early season P after non-mycorrhizal canola, but not after mycorrhizal wheat. Phosphorus fertilization of flax may be more beneficial on soils where P supply is extremely depleted. However, with moderate deficiencies, the benefit is likely to be low. A phosphorus management strategy to maintain P through the rotation by targeting applications to more responsive crops would possibly be more cost-effective than application of P to flax, although where soil P levels are not highly depleted, applications of P to preceding crops may not be needed to improve the yield of the following flax crop.

## INTRODUCTION

Flax is an important crop in Manitoba, Saskatchewan and North Dakota. Phosphorus fertilization of flax can be a problem. Flax is sensitive to seed-placed monoammonium phosphate (Nyborg and Hennig 1969) and does not tend to proliferate its roots in a fertilizer reaction zone (Strong and Soper 1974) so is not efficient at utilizing fertilizer P. Flax is more reliant on residual soil P (Kalra and Soper 1968) unless the soil is very deficient and the bands are positioned within 2.5 to 5.0 cm of the seed-row (Sadler 1980). Broadcast applications of P also do not generally increase flax yield (Grant and Bailey 1993).

Reduced tillage systems are becoming increasingly popular because they can conserve soil moisture, increase crop yield potential, improve soil quality and reduce time, labour and equipment costs in farming operations. Flax often responds very well to reduced tillage systems. Research at Guelph (Miller 2000) showed that mycorrhizal activity could be increased by using reduced tillage or by following a mycorrhizal crop, leading to improved early season P nutrition. Mycorrhizal associations could be responsible for part of the positive response that flax shows in no-till systems. Phosphorus fertility requirements in flax could be affected by tillage system and by whether the preceding crop was mycorrhizal.

Flaxseed is relatively high in Cd (Grant et al. 2000), which is not desirable if flax is destined for human consumption. High Cd concentration may make it difficult to increase flax movement into the health food market. Phosphorus fertilization and preceding crop can influence Cd concentration of flax (Grant et al. 1999).

This study was conducted to determine the interactive effects of tillage system, preceding crop, level of P fertilization in preceding crop and side-banded P fertilization on the early season P nutrition, mycorrhizal development, seed yield and seed Cd concentration of flax.

## MATERIALS AND METHODS

Trials were initiated in 1999, on two clay loam soils, one which had been under no-till management for 6 years and a second that had been under conventional tillage management. Canola (nonmycorrhizal crop) and wheat (mycorrhizal crop) were grown under conventional (CT) and no-till (NT) management in a split plot design, with tillage as the main block treatment. Monoammonium phosphate (MAP) fertilizer was side-banded at 0, 25 and 50 kg $P_2O_5$ $ha^{-1}$ with the canola and wheat. Crop and P treatments were randomized in the tillage systems, in 2 m by 5 m plots, with 2 subplots of each treatment in 4 reps. Flax was seeded with or without 25 kg $P_2O_5$ $ha^{-1}$ as side-banded MAP on the canola or wheat plots from the previous year.

Plots were seeded with a SeedHawk plot seeder, with hoe-openers on 20 cm spacing and. P fertilizer placed approximately 2.0 cm to the side and 3.0 cm below the seed-row. Flax received 70 kg N $ha^{-1}$ and canola and wheat 100 kg N $ha^{-1}$ as ammonium nitrate pre-plant banded before seeding. Canola also received 20 kg S $ha^{-1}$ as ammonium sulphate in the pre-plant band. The N in the monoammonium phosphate and ammonium sulphate was balanced in the pre-plant N application. Pre-emergence burn-off and in-crop herbicides were applied following provincial recommendations to control the spectrum of weeds present. Biomass yield and nutrient content of flax tissue was assessed at 5 weeks. Mycorrhizal association was measured in 2001 and 2002 by determining the percentage of the flax root colonized at five weeks in 10 plants selected at random within the plot. Seed yield was measured by harvesting the centre 5 rows of the plots using a plot combine. Statistical analysis was conducted using Proc Mixed of SAS.

## RESULTS AND DISCUSSION

### Stand Density

Preceding crop had a dominant influence on stand density over the three-year study with stand density being higher if flax was grown after wheat rather than canola (data not presented). The effects of fertilizer and tillage were minor and erratic compared to the effect of preceding crop.

Table 1: 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 Flax | Residual P | CT | NT | Mean | CT | NT | Mean | CT | NT | Mean | CT | NT | Mean |
| 0 | 0 | 0.46 | 0.38 | 0.42 | 0.48 | 0.49 | 0.48 | 0.38 | 0.36 | 0.37 | 0.34 | 0.33 | 0.34 |
| 0 | 25 | 0.45 | 0.43 | 0.44 | 0.50 | 0.49 | 0.49 | 0.40 | 0.36 | 0.38 | 0.38 | 0.37 | 0.37 |
| 0 | 50 | 0.47 | 0.46 | 0.47 | 0.48 | 0.48 | 0.48 | 0.44 | 0.36 | 0.40 | 0.39 | 0.43 | 0.41 |
| **Mean of 0 P** | | **0.46** | **0.42** | **0.44** | **0.48** | **0.49** | **0.49** | **0.41** | **0.36** | **0.38** | **0.37** | **0.38** | **0.37** |
| 25 | 0 | 0.45 | 0.45 | 0.45 | 0.50 | 0.48 | 0.49 | 0.41 | 0.36 | 0.38 | 0.37 | 0.36 | 0.37 |
| 25 | 25 | 0.48 | 0.46 | 0.47 | 0.52 | 0.51 | 0.51 | 0.39 | 0.37 | 0.38 | 0.39 | 0.39 | 0.39 |
| 25 | 50 | 0.50 | 0.46 | 0.48 | 0.53 | 0.54 | 0.53 | 0.46 | 0.38 | 0.42 | 0.42 | 0.43 | 0.43 |
| **Mean of 25 P** | | **0.48** | **0.45** | **0.47** | **0.52** | **0.51** | **0.51** | **0.42** | **0.37** | **0.40** | **0.39** | **0.39** | **0.39** |
| **Mean across P** | | **0.47** | **0.44** | **0.45** | **0.50** | **0.50** | **0.50** | **0.41** | **0.36** | **0.39** | **0.38** | **0.38** | **0.38** |

**Flax Tissue Concentration**

Phosphorus is needed during the early growth of crops for optimum crop yield. Early-season flax tissue P concentration was higher after wheat than canola at the Research Centre site ($p<0.0001$), but not at the MZTRA site (Table 1). At both sites, tissue P at five weeks was higher under CT than NT after canola, but did not differ with tillage after wheat. Cooler soil conditions may reduce the P availability under no-till. When the preceding crop is mycorrhizal, as wheat is, enhanced mycorrhizal activity may allow the flax to increase P uptake to compensate for the lower P availability under NT. Side-banded P in flax increased the tissue P concentration at five weeks ($p<0.014$). Phosphorus applied to the preceding crop also increased flax tissue P concentration ($p<0.001$). Applying 25 kg $P_2O_5$ $ha^{-1}$ in the preceding crop produced similar tissue P concentration to 25 kg $ha^{-1}$, side-banded with the flax at seeding. Therefore flax could use both residual and side-banded P early in the growing season.

Table 2: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on biomass yield at five weeks (kg $ha^{-1}$) at two locations (2000-2002).

| | | Research Centre | | | | | | MZTRA | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Canola | | | Wheat | | | Canola | | | Wheat | | |
| P in Flax | Residual P | CT | NT | Mean | CT | NT | Mean | CT | NT | Mean | CT | NT | Mean |
| 0 | 0 | 254 | 312 | 283 | 372 | 439 | 405 | 522 | 645 | 584 | 814 | 919 | 867 |
| 0 | 25 | 271 | 316 | 294 | 319 | 400 | 359 | 500 | 709 | 605 | 774 | 890 | 832 |
| 0 | 50 | 255 | 278 | 266 | 410 | 406 | 408 | 484 | 671 | 577 | 769 | 948 | 859 |
| **Mean of 0 P** | | **260** | **302** | **281** | **367** | **415** | **391** | **502** | **675** | **589** | **786** | **919** | **852** |
| 25 | 0 | 283 | 374 | 328 | 432 | 526 | 479 | 506 | 635 | 571 | 802 | 937 | 869 |
| 25 | 25 | 289 | 416 | 353 | 433 | 409 | 421 | 526 | 650 | 588 | 842 | 894 | 868 |
| 25 | 50 | 261 | 352 | 306 | 403 | 482 | 443 | 469 | 623 | 546 | 719 | 878 | 799 |
| **Mean of 25 P** | | **278** | **380** | **329** | **423** | **472** | **448** | **500** | **636** | **568** | **787** | **903** | **845** |
| **Mean across P** | | **269** | **341** | **305** | **395** | **444** | **419** | **501** | **656** | **578** | **786** | **911** | **849** |

**Five Week Biomass**

The major factor affecting early season flax growth at both locations was preceding crop, with biomass being far higher after wheat than after canola at both locations ($p<0.0001$). Early season growth was higher at both locations under NT as compared to CT ($p<0.0007$). Early season biomass production was increased by P application in flax at the Research Centre site ($p<0.0001$), but not at the MZTRA site (Table 2). Access to P near the root early in the growing season was apparently beneficial to the flax on the low-P soil at the Research Centre.

**Mycorrhizal Association**

Mycorrhizal incidence (%) in 2001 was greater when the flax followed wheat than when it followed canola at both locations, although the difference was greater at the Research Centre than the Zero-till Farm (Table 3). Nonmycorrhizal crops such as canola can reduce mycorrhizal incidence in following crops. Association was greater with NT than CT at the Zero-till Farm after both of the preceding crops and at the Research Centre after canola. There was no effect of tillage system at the Research Centre after wheat. The level of mycorrhizal association was very high after wheat at the Research Centre, so it is possible that the tillage system had no effect due to the high degree of association present in wheat stubble. Association was reduced at both locations by side-banded P fertilization in the flax, with an interesting tendency ($p<0.06$) for mycorrhizal association to increase with residual P at the Research Centre and decrease with residual P at the Zero-till Farm.

Table 3: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on mycorrhizal incidence (% of root area covered) at two locations (2001).

| | | Research Centre | | | | | | MZTRA | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Canola | | | Wheat | | | Canola | | | Wheat | | |
| P in Flax | Residual P | 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** |

Table 4: Effect of P application to flax, P application in the preceding crop, type of preceding crop and tillage system on mycorrhizal incidence ($mm^2$ per root) at two locations (2002).

| | | Research Centre | | | | | | MZTRA | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Canola | | | Wheat | | | Canola | | | Wheat | | |
| P in Flax | Residual P | CT | NT | Mean | CT | NT | Mean | CT | NT | Mean | CT | NT | Mean |
| 0 | 0 | 123.8 | 170.0 | 146.9 | 154.9 | 196.2 | 175.5 | 93.0 | 185.6 | 139.3 | 103.7 | 196.2 | 149.9 |
| 0 | 25 | 101.0 | 122.1 | 111.6 | 129.1 | 180.7 | 154.9 | 87.6 | 138.9 | 113.2 | 99.3 | 209.3 | 154.3 |
| 0 | 50 | 87.8 | 131.4 | 109.6 | 126.1 | 215.4 | 170.7 | 154.8 | 178.2 | 166.5 | 130.9 | 259.4 | 195.1 |
| **Mean of 0 P** | | **104.2** | **141.2** | **122.7** | **136.7** | **197.4** | **167.0** | **111.8** | **167.6** | **139.7** | **111.3** | **221.6** | **166.4** |
| 25 | 0 | 144.3 | 162.3 | 153.3 | 143.6 | 269.4 | 206.5 | 124.7 | 267.2 | 195.9 | 163.6 | 242.1 | 202.9 |
| 25 | 25 | 134.7 | 197.7 | 166.2 | 192.2 | 220.5 | 206.4 | 131.4 | 173.0 | 152.2 | 106.7 | 197.5 | 152.1 |
| 25 | 50 | 97.2 | 137.4 | 117.3 | 124.5 | 198.3 | 161.4 | 119.1 | 278.5 | 198.8 | 157.4 | 252.6 | 205.0 |
| **Mean of 25 P** | | **125.4** | **165.8** | **145.6** | **153.4** | **229.4** | **191.4** | **125.1** | **239.6** | **182.3** | **142.6** | **230.7** | **186.6** |
| **Mean across P** | | **114.8** | **153.5** | **134.2** | **145.1** | **213.4** | **179.2** | **118.4** | **203.6** | **161.0** | **126.9** | **226.2** | **176.5** |

Similar effects were apparent when the area of root colonized by mycorrhizae ($mm^2$ per root) was measured in 2002 (Table 4). Colonization was much higher in flax grown after wheat than canola at both locations ($p<0.0001$) and was much higher under NT than CT at both locations ($P<0.03$). Colonized area decreased with residual P at the Research Centre site ($p<0.0.0003$), particularly after canola, while at the MZTRA site, there was a reduction with the low rate of residual P, but not with the high rate ($p<0.0066$). Application of P with the flax did not reduce mycorrhizal colonization and led to a slight increase at the Research Centre site ($p<0.03$). The dominating effect on mycorrhizal association in both years was the type of preceding crop.

Table 5: 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 (2000-2002).

| | | Research Centre | | | | | | MZTRA | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Canola | | | Wheat | | | Canola | | | Wheat | | |
| P in Flax | Residual P | CT | NT | Mean | CT | NT | Mean | CT | NT | Mean | CT | NT | Mean |
| 0 | 0 | 1557 | 1568 | 1563 | 1568 | 1775 | 1672 | 1593 | 1384 | 1488 | 1883 | 1737 | 1810 |
| 0 | 25 | 1491 | 1691 | 1591 | 1663 | 1667 | 1665 | 1503 | 1385 | 1444 | 1814 | 1843 | 1829 |
| 0 | 50 | 1528 | 1535 | 1531 | 1678 | 1741 | 1709 | 1652 | 1385 | 1518 | 1714 | 1771 | 1742 |
| Mean of 0 P | | 1525 | 1598 | 1562 | 1636 | 1728 | 1682 | 1582 | 1384 | 1483 | 1804 | 1783 | 1794 |
| 25 | 0 | 1509 | 1587 | 1548 | 1687 | 1700 | 1694 | 1702 | 1333 | 1517 | 1853 | 1799 | 1826 |
| 25 | 25 | 1579 | 1615 | 1597 | 1820 | 1794 | 1807 | 1490 | 1491 | 1491 | 1927 | 1605 | 1766 |
| 25 | 50 | 1606 | 1565 | 1585 | 1806 | 1776 | 1791 | 1495 | 1341 | 1418 | 1950 | 1820 | 1885 |
| Mean of 25 P | | 1565 | 1589 | 1577 | 1771 | 1757 | 1764 | 1562 | 1388 | 1475 | 1910 | 1742 | 1826 |
| Mean across P | | 1545 | 1593 | 1569 | 1704 | 1742 | 1723 | 1572 | 1386 | 1479 | 1857 | 1762 | 1810 |

**Seed Yield**

Flax seed yield was primarily influenced by preceding crop at both locations (Table 5). When averaged over the three years of the study, seed yield was 9.8% higher after wheat than after canola at the Research Centre site and 22% higher after wheat than after canola at the MZTRF site. The effect was evident from crop emergence, through early season growth, to final straw and seed yield. The effect may be due to a number of factors, including some degree of allelopathy from canola residue, early season competition from volunteer canola plants or restriction in mycorrhizal colonization after canola. Seed yield at the Research Centre tended ($p<0.0655$) to be higher when P was applied to the flax, although the difference was small (3%), while there was no significant effect at the MZTRA site. Effects of residual P were also minor relative to the effect of the preceding crop. Seed yield tended ($P<0.0812$) to be higher at the MZTRF when flax was grown under conventional tillage rather than no-till, possibly because of the effects of weed competition or cool soil temperatures in the early stages of crop growth. Application of P fertilizer did not counteract the effect of NT.

Table 6: Effect of P to flax, P application in the preceding crop, type of preceding crop and tillage system on seed Cd concentration (mg kg$^{-1}$) at two locations (2000-2002).

| | | Research Centre | | | | | | MZTRA | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Canola | | | Wheat | | | Canola | | | Wheat | | |
| P in Flax | Residual P | CT | NT | Mean | CT | NT | Mean | CT | NT | Mean | CT | NT | Mean |
| 0 | 0 | 349 | 270 | 310 | 302 | 240 | 271 | 241 | 212 | 226 | 199 | 192 | 195 |
| 0 | 25 | 304 | 298 | 301 | 271 | 217 | 244 | 265 | 217 | 241 | 209 | 199 | 204 |
| 0 | 50 | 437 | 288 | 363 | 275 | 228 | 252 | 262 | 250 | 256 | 214 | 195 | 205 |
| Mean of 0 P | | 364 | 285 | 324 | 283 | 228 | 256 | 256 | 226 | 241 | 207 | 195 | 201 |
| 25 | 0 | 315 | 304 | 309 | 300 | 247 | 273 | 262 | 239 | 250 | 205 | 200 | 203 |
| 25 | 25 | 368 | 333 | 351 | 316 | 289 | 303 | 262 | 269 | 265 | 223 | 217 | 220 |
| 25 | 50 | 399 | 282 | 341 | 293 | 265 | 279 | 272 | 250 | 261 | 226 | 211 | 218 |
| Mean of 25 P | | 360 | 307 | 334 | 303 | 267 | 285 | 265 | 253 | 259 | 218 | 209 | 214 |
| Mean across P | | 362 | 296 | 329 | 293 | 248 | 270 | 260 | 240 | 250 | 213 | 202 | 208 |

**Cadmium Concentration of Flaxseed**

Flaxseed Cd was higher after canola than wheat at both locations ($p<0.0001$) (Table 6). Flaxseed Cd also was numerically higher under NT than CT, but the effect was not statistically significant at either location. Other management practices did not significantly affect seed Cd content at the Research Centre site, but Cd concentration increased with P application in flax ($p<0.0001$) and with residual P ($p<0.0007$) at the MZTRF, largely due to lower standard error at the MZTRF. The magnitude of the effect of fertilizer management on Cd was low relative to the effect of preceding crop.

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## REFERENCES

Grant, C.A. and Bailey, L.D. 1993. Interactions of zinc with banded and broadcast phosphorus fertilizer on the dry matter and seed yield of oilseed flax. Can. J. Plant Sci. 73:7-15.

Grant, C.A., Bailey, L.D., McLaughlin, M.J. and Singh, B.R. 1999. Management factors which influence cadmium concentrations in crops. In: McLaughlin, M.J. and Singh, B.R. (Editors) Cadmium in Soils and Plants. Kluwer Academic Publishers. Dordrecht, The Netherlands. Pp. 151-198.

Grant, C.A., Dribnenki, J.C.P and Bailey, L.D. 2000. Cadmium and zinc concentration and ratios in seed and tissue of solin and flax as affected by nitrogen and phosphorus fertilizer and Provide (*Penicillium bilaji*). J. Sci. Fd. Agric. 80: 1-9.

Kalra, Y. P. and Soper, R. J. 1968. Efficiency of rape, oats, soybeans and flax in absorbing soil and fertilizer phosphorus at seven stages of growth. Agron. J. 60: 209-212.

Miller, M. H. 2000. Arbuscular mycorrhizae and the phosphorus nutrition of maize: A review of Guelph studies. Can. J. Plant Sci. 80: 47-52.

Nyborg, M. and Hennig, A. M. F. 1969. Field experiments with different placements of fertilizers for barley, flax and rapeseed. Can. J. Soil Sci. 49: 79-88.

Sadler, J.M. 1980. Effect of placement location for phosphorus banded away from the seed on growth and uptake of soil and fertilizer phosphorus by flax. Can. J. Soil Sci. 251-262.

Strong, W. M., and Soper, R. J. 1974. Phosphorus utilization by flax, wheat, rape, and buckwheat from a band or pellet-like application. I. Reaction zone proliferation. Agron. J. 66: 597-601.