

Evaluation of Fibre Flax (*Linum usitatissimum* L.) Performance under Minimal and Zero Tillage in Eastern Canada

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With 4 tables

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Abstract

The feasibility of producing fibre flax in minimum tillage or zero tillage (ZT) systems was investigated. The results were variable between the sites, which differed in soil type and previous cropping history. Tillage regime had no impact on fibre flax phenological development including number of days to emergence, days to flowering and days to harvest at either site. However, tillage regime had a significant effect on mean stem diameter, dry matter content and plant height at all three sampling dates at the sandy loam site, and a significant effect on mid-season plant height at the clay site. At the sandy loam site, ZT plots had the highest populations of plants with the finest stem diameters, the lowest branching ratios, but the shortest plants by the end of the season. Overall, plant densities were greater, stem diameters thinner, and biomass production higher in the heavier soil of the clay site. These results indicate that under the growing conditions present in 1998, fibre flax can successfully be grown in minimum or ZT systems on different soil types in Eastern Canada. Moreover, the growth of fibre flax in these systems does not compromise the proportion of tall plants having thin stems and minimal branching, a critical quality parameter for fibre flax production.

Key words: Canada — fibre flax — growth — *Linum usitatissimum* — tillage — yield

Introduction

Reduced tillage is a concept that has been practised for many decades (Baker et al. 1996), but only recently, and for a variety of reasons, have producers increasingly adopted reduced tillage as a mainstay of their crop management practices (Lafond et al. 1996). Reduced soil erosion and improved water infiltration are two benefits that

can directly be attributed to increased crop residues on the soil surface (Lafond 1993, Lafond et al. 1993). Other potential advantages of reduced tillage include lower fuel costs, greater time flexibility at seeding, enhanced soil structure and increased soil organic matter levels (Baker et al. 1996).

Tillage practices can have a large effect on seedbed quality, with conventional tillage (CT) most often resulting in a loose, friable seedbed (Baker et al. 1996). This contrasts with direct seeding or zero tillage (ZT), in which seedbeds tend to be crustier and more compact, with a substantial amount of crop residue remaining on the surface. Minimum tillage systems tend to occupy an intermediate position between conventional and ZT systems with seedbeds having a lumpy to fine consistency, depending on the extent of residue management and crops employed in the rotation.

Early and uniform establishment is crucial to the success of fibre flax crops. Flax is often seeded at rates to attain final densities of 2000 plants m⁻² (Sultana 1983, Robert 1995, Stephens 1997, Couture et al. 2002), so even a partial delay in emergence can result in a highly non-uniform stand, as plants which emerge late are at a competitive disadvantage (Fowler 1984). Uniformity is a desirable characteristic in fibre flax destined for linen production, as the length of fibres will influence the price a producer obtains for the crop (Ulrich and Laugier 1995). Both seedbed preparation and seed placement influence stand uniformity (Lafond et al. 1996, Couture 1999).

Establishment and yield of oilseed flax can be relatively high in reduced tillage systems (Gubbels and Kenaschuk 1989a,b, Lafond et al. 1993). Despite these findings using oilseed flax, little is known about the performance of fibre flax within a reduced tillage rotation system. Although flax is a cool season crop with moderate frost hardiness (Fouilloux 1989), deep seeding in cool, moist soils characteristic of minimum or ZT systems can result in both delayed emergence and lower stand density (O'Connor and Gusta 1994).

Hence, the performance of fibre flax (cv. Ariane) was evaluated under Eastern Canadian growing conditions and in three different tillage systems: CT (minimum of two tillage operations), minimum tillage (MT, maximum of two tillage operations) and direct seeding or ZT (no tillage operations).

Materials and Methods

Research was conducted in 1998 at two sites at the Emile A. Lods Agronomy Research Centre of Macdonald Campus, Canada (45°25'N, 73°56'W). One site was located on a Bearbrook clay soil (poorly drained, dark grey gleysolic, pH 6.5) (Lajoie 1960), which was planted with soya bean in 1997 (hereafter referred to as the clay site) and barley in 1996. The second site was located on a Chicot fine sandy loam (moderately well drained, grey brown podzolic, pH 5.9) (Lajoie 1960), which was planted with oats in 1997 (hereafter referred to as the sandy loam site) and with red clover in 1995 and 1996.

The three tillage regimes used for this study were considered the treatments and were arranged in a randomized complete block design with four blocks and one replicate/treatment/block. The tillage regimes used follow the classification suggested by Lafond et al. (1996) where each tillage type is based on the distinct number of tillage operations.

For each field, the CT plots were subjected to a fall mouldboard ploughing in the autumn of 1997 followed by disking and cultivation in the spring of 1998. The MT plots were disked once and then a second time at an angle of 90° in the spring of 1998. The ZT plots received no cultivation, and no pre-plant herbicide application was required because of early seeding and the absence of emerged weeds. No fertilizer was applied at either site. The fibre flax cultivar 'Ariane' was seeded on 1 May at a rate of 125 kg ha⁻¹ in all plots on the same day using a Hassia DU 100 small grains drill (Hassia, Butzbach, Germany) for the CT and MT plots, and a Great Plains no till seeder (Great Plains Manufacturing, Salinas, KS) for the ZT plots. Plot size was 3 m × 20 m. Row spacing was 6.5 and 25 cm for the Hassia seeder and the Great Plains seeder, respectively.

The sandy loam site was moderately infested with quackgrass [*Elytrigia repens* (L.) Nevski] and was sprayed with fluazifop-p-butyl (Zeneca AGRO, Calgary, Alta, Canada) + non-ionic surfactant (0.7 kg ai ha⁻¹ + 0.5 %

v/v) on 28 May. The field was sprayed again with bentazon (BASF Canada Inc., London, Ont., Canada) (0.960 kg ai ha⁻¹) for annual broadleaf weed control on 4 June. The clay site was sprayed with bentazon (1.08 kg ha⁻¹) for control of yellow nutsedge (*Cyperus esculentus* L.) on 4 June. All herbicide treatments were applied at recommended rates for oilseed flax in Ontario (Anonymous 1997).

The data collected were used to assess the performance of fibre flax under reduced tillage compared with CT. The number of days to emergence, days to flowering and days to harvest were determined for plants in each treatment and were considered as measures of development. At least 50 % of plants in each plot had to be in flower for the plot to be considered as 'in flower'. Mean plant height in each plot was determined at 3, 6 and 9 weeks post-emergence by holding approximately eight to 12 plants together against a meter-stick and estimating their average height. Height was determined by measuring plants from the soil level to the uppermost growing point. The mean height per plot was the average of two observations. Stem diameters were measured on 24 July (sandy loam site) and 30 July (clay site) on 50 randomly selected plants per plot using an electronic digital calliper (Marathon Management Co., Richmond Hill, Ont., Canada), and plot means used for data analysis. Plant densities were determined in two randomly selected 0.4 m² sub-plots within each treatment plot. A branching ratio value was determined by dividing the total number of plants in the sub-plots by the number of plants having branches. Branching ratio and plant density data were subjected to a square root + 1-transformation before analysis to improve the normality requirement of ANOVA (Gomez and Gomez 1984). Fresh yield data were obtained from two randomly placed 0.4 m² sub-plots within each plot and bulked. A 200 g sample from each plot was then dried to constant weight at 65 °C in a forced air dryer to determine the dry matter weight.

All data were subjected to ANOVA using the GLM procedure (SAS Institute, Inc. 1985) to identify main effects of tillage regime on the parameters measured. Significant results (P < 0.05) were then subjected to a Tukey's HSD means comparison procedure (Motulsky 1995) to identify differences between treatments.

Results

Meteorological data

April 1998 was considerably warmer and drier than the 20-year average for this month. The mean temperature was 2 °C above normal, with only a quarter of the normal rainfall, thus allowing seeding to take place relatively early. Temperatures were above normal from April to September, except for July, which was 1 °C below normal. The same pattern was observed for rainfall, with every month having below-normal precipitation, except for June, which had 1.5 times the normal rainfall. The season-long number of growing

degree days (GDD) (base 5 °C) was 1828, 143 GDD below the 20-year average of 1971 GDD.

Sandy loam site

Tillage treatment had little effect on fibre flax emergence as all plots had uniform seedling emergence at 6 days after seeding (Table 1). The number of days to flowering varied little; with plants in the ZT plots flowering in 51 days compared with 53 and 54 days for plants in the MT and CT plots, respectively (Table 1). The number of days to harvest was 85 days for all tillage treatments (Table 1). There were no significant ($P \geq 0.05$) differences in plant density, branching ratio or fresh weight between treatments (Tables 2 and 3). However, the percentage of fibre flax dry matter varied significantly between treatments (Table 3). Plants in the ZT plots had the highest dry matter content (38 %) compared with 34 and 33 % for plants in the CT and MT plots, respectively (Table 3). Stem diameter also differed significantly

between treatments (Table 2). Plants in the ZT plots had the lowest mean stem diameter (1.87 mm) compared with plants in the CT plots (2.21 mm) and the MT plots (2.07 mm) (Table 2). Tillage regime had a significant ($P < 0.01$) effect on plant height at all three sampling dates (Table 4). Plants in the ZT plots (11.9 cm) and MT plots (11.1 cm) were taller than plants in the CT plots (9.5 cm) for the first sample date (Table 4). At the second sample date, the tallest plants (45.3 cm) were found in the MT plots while the shortest plants (37.1 cm) were found in the ZT plots (Table 4). Plants in the CT plots were of intermediate height (42.2 cm). A similar pattern was found at the final sample date, with plants in the MT plots tallest (84.9 cm), CT plants of intermediate height (83.4 cm) and ZT plants shortest (79.8 cm) (Table 4).

Clay site

All plots showed consistent emergence of flax seedlings 6 days after seeding, regardless of tillage

Table 1: Phenological development of fibre flax (cv. Ariane) in two Québec sites and under three tillage systems

Treatment	Clay site			Sandy loam site		
	Days to emergence	Days to flowering	Days to harvest	Days to emergence	Days to flowering	Days to harvest
CT	6	56	96	6	54	85
MT	6	56	96	6	53	85
ZT	6	54	96	6	51	85
Mean	6	55.3	96	6	52.7	85

CT, conventional tillage; MT, minimum tillage; ZT, zero tillage.

Table 2: Mean fibre flax density, branching ratio and stem diameter at two Québec sites as affected by three tillage regimes

Treatment	Plant density (m ²)		Branching ratio		Stem diameter (mm)	
	Sandy loam	Clay	Sandy loam	Clay	Sandy loam	Clay
CT	1253	1689	0.007	0.024	2.21 a	1.94
MT	1233	1475	0.017	0.029	2.07 ab	1.86
ZT	1311	1683	0.004	0.003	1.87 b	1.93
MSD	–	–	–	–	0.33	–
Tillage	NS	NS	NS	NS	*	NS
CV	11.1	8.8	1.0	2.7	2.7	9.0

CT, conventional tillage; MT, minimal tillage; ZT, zero tillage; MSD, minimum significant difference; NS, not significant; CV, coefficient of variation.

*Significant at $P < 0.05$.

Values within a column followed by the same letter do not differ at $P \geq 0.05$, according to Tukey's HSD test.

Table 3: Mean yield of fibre flax at two Québec sites as affected by three tillage regimes

Treatment	Fresh weight (t ha ⁻¹)		Dry matter content (%) ¹	
	Sandy loam	Clay	Sandy loam	Clay
CT	19.3	26.8	34 b	37
MT	27.4	30.2	33 b	36
ZT	17.2	26.4	38 a	35
MSD	–	–	–	–
Tillage	NS	NS	*	NS
CV	11.3	1.5	6.3	4.8

CT, conventional tillage; MT, minimum tillage; ZT, zero tillage; NS, not significant; MSD, minimum significant difference; CV, coefficient of variation.

* Significant at $P < 0.05$.

¹ Mean comparison based on dry weights, not percentages.

Values within a column followed by the same letter do not differ at $P \geq 0.05$, according to Tukey's HSD test.

treatment (Table 1). Fibre flax plants in the ZT plots were flowering after 54 days, and in the MT and CT plots, after 56 days (Table 1). All plots were harvested 96 days after seeding (Table 1). There were no significant effects of tillage on plant density, branching ratio, stem diameter, fresh weight, or percentage dry matter (Tables 2 and 3). Similarly, no significant differences in plant height were found at either the first or third sample date (Table 4). However, plants in the ZT plots had a mean height of 42.1 cm at the second sample date, which was significantly greater than mean plant heights for the CT (37.1 cm) and MT (34.1 cm) plots (Table 4).

Discussion

Due to the unusually warm weather in early spring 1998, seeding occurred during the third week of April. Low soil temperatures such as are often found in ZT systems in early spring are problematic for crop production as they can retard crop emergence and reduce seedling vigour (O'Connor and Gusta 1994, Lafond et al. 1996). However, this factor was likely not important at either of our study sites as all three tillage treatments produced uniform emergence of fibre flax seedlings within 6 days of planting. There was also little difference within a site and between sites in the number of days plants required to attain the flowering stage. Plants at the clay site however, required an additional 11 days to reach maturity, relative to the plots at the sandy loam site. The delay in plants attaining maturity at the soya bean site may have been due to the increased nitrogen available for vegetative growth on this site that was previously grown to a soya bean crop. This delayed effect of flax maturation on soils previously planted with soya bean has been observed in other trials in the region (S. J. Couture, personal observation).

Findings between the two sites were inconsistent, although tillage effects were generally more pronounced at the sandy loam site than at the clay site. There were also important differences in the magnitude of some of the parameters measured between the sites. Unfortunately, because of significant within-site variability as determined by Bartlett's test, we were unable to verify this effect statistically (Gomez and Gomez 1984). For example, yields in MT plots were similar at both sites.

Table 4: Mean height of fibre flax plants at different sampling dates at two Québec sites as affected by three tillage regimes

Treatment	Height (cm) 3 weeks post-emergence		Height (cm) 6 weeks post-emergence		Height (cm) 9 weeks post-emergence	
	Sandy loam	Clay	Sandy loam	Clay	Sandy loam	Clay
CT	9.5 b	9.6	42.2 ab	37.1 b	83.4 ab	83.4
MT	11.1 a	10.0	45.3 a	34.1 b	84.9 a	83.9
ZT	11.9 a	10.5	37.1 b	42.1 a	79.8 b	81.5
MSD	1.5	–	6.2	3.6	3.9	–
Tillage	**	NS	**	***	**	NS
CV	16.0	15.1	17.5	11.2	5.5	5.1

CT, conventional tillage; MT, minimum tillage; ZT, zero tillage; NS, not significant; MSD, minimum significant difference; CV, coefficient of variation.

Significant at ** $P < 0.01$ and *** $P < 0.001$, respectively.

Values within a column followed by the same letter do not differ at $P \geq 0.05$, according to Tukey's HSD test.

However, the ZT and CT plots yielded 9 and 7 t ha⁻¹ more fresh biomass, respectively, at the clay site than at the sandy loam site. In fact, overall yields at the clay site were greater than at the sandy loam site. These results are consistent with previous findings suggesting fibre flax yields more biomass (Hocking et al. 1987), as well as yielding more and higher quality fibres on slightly heavier soils (Elhaak et al. 1999). Our findings are more than likely due to the combined effects of higher soil nitrogen levels at the clay site and an increased ability of the heavier clay soil at this site to retain nutrients and moisture relative to the sandy loam soil.

Differences between the two sites were also observed for plant density, branching ratio and stem diameter. Plant density was greater across all tillage treatments at the clay site with stem diameters correspondingly lower at this site compared with the sandy loam site. However, for undetermined reasons, mean branching ratios were much greater at the clay site, which is inconsistent with reports that greater plant densities result in plants with fewer branches (Hocking et al. 1987). However, our results agree with work showing that ample nitrogen and moisture availability can increase branching in flax plants even at relatively high population densities (Hassan and Leitch 2001).

Comparison of tillage systems in oilseed flax in Western Canada indicates notable growth and (grain) yield advantages for flax grown in ZT systems compared with CT systems (Gubbels and Kenaschuk 1989a,b, Lafond 1993). Our results suggest that fibre flax grown in a ZT system would produce shorter plants having less biomass, leading to fewer and shorter fibres overall, which is consequential for linen production but not for industrial use (Foster et al. 1997, 1998). Interestingly, plants in the ZT plots in both sites had a greater mean plant height at 3 weeks post-emergence at the sandy loam site, and until 6 weeks post-emergence at the clay site. This suggests that concerns of lower soil temperatures negatively affecting plant development did not materialize in our sites during the warm growing season in 1998. Plant densities were also greater in the ZT plots due, in part, to the higher plant populations within rows, which is consistent with the findings of Gubbels and Kenaschuk (1989a,b). Higher plant densities in ZT plots at the two sites, likely decreased average stem diameters and branching ratios of fibre flax plants as intraspecific plant

competition for light became more intense. Easson and Long (1992) reported similar effects of intra-specific plant competition in fibre flax, also observing reduced overall plant height. Diepenbrock and Pörksen (1992) found greater stem diameters in oilseed flax plants grown at lower (200 and 400 plants m⁻²) vs. higher densities (800 and 1200 plants m⁻²).

In this study, there was generally no effect of tillage treatment on fresh weight or branching ratio at either site suggesting that the quantity and quality of fibre is likely not influenced by tillage practices under the soil and growing conditions tested. The results at the sandy loam site indicate that a greater plant density may offset the lower yield and mean plant height in the ZT treatment. Differences between treatments were less pronounced at the clay site, with fresh biomass yield, plant density and final plant height not affected by tillage regime. However, plants within the MT treated plots yielded the highest fresh biomass, despite these plots having the lowest mean plant densities of all tillage treatments. These findings indicate that fibre flax could be produced successfully in a reduced tillage or ZT system; however, a seeder with a narrower row spacing than 25 cm would be advantageous, and would likely result in higher population densities, and ultimately taller plants. In drawing a parallel between oilseed flax and fibre flax, many authors report that varying years and location have a greater influence on flax productivity than varying production practices (Diepenbrock et al. 1995) and this cannot be discounted in our single-year study.

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References

- Anonymous, 1997: Publication 75. Ontario Guide to Weed Control 1998. Ontario Ministry of Agriculture, Food, and Rural Affairs. Queen's Printer (Ontario), Toronto.
- Baker, C. J., K. E. Saxton, and W. R. Ritchie, 1996: No-tillage Seeding: Science and Practice. CAB International University Press, Cambridge.

- Couture, S. J., 1999: Agronomic aspects of fibre flax production in Québec. MSc Thesis, McGill University, Montréal.
- Couture, S. J., W. L. Asbil, A. DiTommaso, and A. K. Watson, 2002: Comparison of European fibre flax (*Linum usitatissimum*) cultivars under Eastern Canadian growing conditions. *J. Agron. Crop Sci.* **188**, 350—356.
- Diepenbrock, W., and N. Pörksen, 1992: Phenotypic plasticity in growth and yield components of linseed (*Linum usitatissimum* L.) in response to spacing and N-nutrition. *J. Agron. Crop Sci.* **169**, 46—60.
- Diepenbrock, W. A., J. Léon, and K. Clasen, 1995: Yielding ability and yield stability of linseed in central Europe. *Agron. J.* **87**, 84—88.
- Easson, D. L., and F. N. J. Long, 1992: The effect of time of sowing, seed rate and nitrogen level on the fibre yield and quality of flax (*Linum usitatissimum* L.). *Irish J. Agric. Food Res.* **31**, 163—172.
- Elhaak, M. A., M. N. El-Shourbagy, and R. El-Nagar, 1999: Effect of edaphic factors on technical properties of flax fibre. *J. Agron. Crop Sci.* **182**, 113—120.
- Foster, R., H. S. Pooni, and I. J. Mackay, 1997: Quantitative evaluation of *Linum usitatissimum* varieties for dual-purpose traits. *J. Agric. Sci.* **129**, 179—185.
- Foster, R., H. S. Pooni, and I. J. Mackay, 1998: Quantitative analysis of *Linum usitatissimum* crosses for dual-purpose traits. *J. Agric. Sci.* **135**, 285—292.
- Fouilloux, G., 1989: Breeding flax methods. In: G. Marshall (ed.), *Flax: Breeding and Utilization*, pp. 14—25. Kluwer Academic Publishers, Dordrecht.
- Fowler, N. L., 1984: The role of germination date, spatial arrangement, and neighbourhood effects in competitive interactions in *Linum*. *J. Ecol.* **72**, 307—318.
- Gomez, K. A., and A. A. Gomez, 1984: *Statistical Procedures for Agricultural Research*, 2nd edn. John Wiley & Sons Inc., New York.
- Gubbels, G. H., and E. O. Kenaschuk, 1989a: Agronomic performance of flax grown on canola, barley, and flax stubble with and without tillage prior to seeding. *Can. J. Plant Sci.* **69**, 31—38.
- Gubbels, G. H., and E. O. Kenaschuk, 1989b: Effect of spring seedling residues on the agronomic performance of subsequent flax and barley crops seeded with and without prior tillage. *Can. J. Plant. Sci.* **69**, 151—159.
- Hassan, F. U., and M. H. Leitch, 2001: Dry matter accumulation in linseed (*Linum usitatissimum* L.). *J. Agron. Crop Sci.* **187**, 83—87.
- Hocking, P. J., P. J. Randall, and A. Pinkerton, 1987: Mineral nutrition of linseed and fiber flax. *Adv. Agron.* **41**, 221—292.
- Lafond, G. P., 1993: The effects of nitrogen, row-spacing and seeding rate on the yield of flax under a zero-till production system. *Can. J. Plant Sci.* **73**, 375—382.
- Lafond, G. P., R. P. Zentner, R. Geremia, and D. A. Derksen, 1993: The effects of tillage systems on the economic performance of spring wheat, winter wheat, flax and field pea production in east-central Saskatchewan. *Can. J. Plant Sci.* **73**, 47—54.
- Lafond, G. P., S. M. Boyetchko, S. A. Brandt, G. W. Clayton, and M. H. Entz, 1996: Influences of changing tillage practices on crop production. *Can. J. Plant Sci.* **76**, 641—649.
- Lajoie, P. G., 1960: Soil Survey of Argenteuil, Two Mountains, and Terrebonne Counties, Québec. Research Branch, Canada Department of Agriculture in cooperation with Québec Department of Agriculture and Macdonald College, McGill University, Montréal.
- Motulsky, H., 1995: *Intuitive Biostatistics*. Oxford University Press, New York.
- O'Connor, B. J., and L. V. Gusta, 1994: Effect of low temperature and seeding depth on the germination and emergence of seven flax (*Linum usitatissimum* L.) cultivars. *Can. J. Plant Sci.* **74**, 247—253.
- Robert, L., 1995: Rapport Annuel 1995 sur la Production de Lin Textile. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, Sainte-Martine.
- SAS Institute, Inc. 1985: *SAS User's Guide: Statistics*, 5th edn. SAS Institute Inc., Cary.
- Stephens, G. R., 1997: *A Manual for Fiber Flax Production*. The Connecticut Agricultural Experiment Station, New Haven.
- Sultana, C., 1983: The cultivation of fibre flax. *Outlook Agric.* **12**, 104—110.
- Ulrich, A., and E. Laugier, 1995: Cottonized flax fiber: preliminary marketing and irrigated production study. Final report to Saskatchewan Agriculture and Food. Agriculture Development Fund Project No. 94000051/33AV, Saskatchewan.