

Influence of Seeding Depth and Seedbed Preparation on Establishment, Growth and Yield of Fibre Flax (*Linum usitatissimum* L.) in Eastern Canada

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With 4 tables

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Abstract

Research was conducted at the Macdonald Campus of McGill University (Québec, Canada) at three sites in 1997 and one site in 1998 to determine the effects and interactions of seeding depth (0, 1, 2, 4 or 6 cm) and seedbed preparation (i.e. soil rolling): none, rolling before or rolling after seeding on fibre flax (cv. Ariane) establishment, growth and yield. Seedbed preparation had little impact on the parameters measured while seeding depth had a variable effect on plant density, plant height, stem diameter and retted straw yield. Seeding depths of 1–4 cm provided consistently good establishment, growth and yield results. In 1997, there was an interaction between seeding depth and seedbed preparation on plant height, branching ratio and retted straw yield, although results were generally variable and tended to be site-specific. In 1998, there was an interaction between seeding depth and seedbed preparation on plant height and stem diameter prior to harvest, with the results varying for all seeding depth–seedbed preparation treatment combinations except for the 2-cm depth treatment. Rolling of the seedbed before seeding on lighter soils and at a depth of 2 cm on most soils can improve establishment, growth and yields of fibre flax under eastern Canadian growing conditions.

Key words: Canada—fibre flax—*Linum usitatissimum*—seedbed preparation—seeding depth—soil rolling

Introduction

Early and uniform establishment is paramount to the success of fibre flax crops for a number of reasons. Fibre flax is seeded at very high densities to attain optimal populations of 2000 plants m⁻² (Sultana 1983, Stephens 1997), so even a partial

delay in emergence can result in highly non-uniform stands as plants emerging late are shorter and at a competitive disadvantage (Fowler 1984). Also, uniformity of plant height is a desirable characteristic in fibre flax destined for linen production because the longer and more uniform the fibres; the more valuable is the crop (Ulrich and Laugier 1995).

Stand uniformity is influenced by seed placement and seedbed preparation (Lafond et al. 1996). Seed placement plays a major role in the time to emergence of flax seedlings and may also impact seedling vigour. Sultana (1983) reported an optimal depth of 2 cm for the sowing of fibre flax. Work by O'Connor and Gusta (1994) on oilseed flax showed that flax sown at a depth of 4 cm required 33 % longer to emerge than flax sown at a depth of 2 cm, and that overall emergence was lower from a depth of 4 cm. Wall (1994) reported reductions of up to 59 % in oilseed flax populations when seeded at depths of 6 cm vs. 3 cm.

One practice commonly used in forage production to improve seedling emergence is the compacting or rolling of the soil before or after seeding as a way to improve seed-to-soil contact and seedbed firmness. This practice is also likely to impact the emergence and early growth of other crop species (Lafond et al. 1996). Results of a study in Québec (Canada) by Robert (1998) suggest that seeding depth and seedbed preparation may be two important factors influencing fibre flax production. For instance, seeds placed too deep in the soil may emerge in a discontinuous manner leading to

uneven crop development and a high proportion of immature plants at harvest. Similarly, a seedbed that is not firm, especially on lighter soils, may also lead to uneven crop emergence and stand development because of poor seed-to-soil contact (Robert 1998).

Hence, the objective of this study was to examine the effects and possible interactions of seeding depth and soil seedbed preparation (rolling) before seeding, after seeding, or not at all, on fibre flax (cv. Ariane) establishment, growth, and yield in a conventional tillage system in Québec (Canada). Although this type of research has been well documented in other parts of the world, this study is part of a larger project examining the feasibility of re-introducing fibre flax production in Canada.

Materials and Methods

The research was conducted in 1997 and 1998 at the Emile A. Lods Agronomy Research Centre of Macdonald Campus (McGill University, Ste-Anne-de-Bellevue, Québec, Canada) (43°25'N, 73°56'W). There were three experimental sites in 1997 and one site in 1998. The first site was located on a Bearbrook clay soil (poorly drained, Dark Gray Gleysolic; pH 5.6–6.4) (Lajoie 1960), the second site was located on a St Amable loamy sand soil (well drained, Gleyified Humo Ferric Podzol; pH 5.0–5.7) (Lajoie 1960), and the third site was located on Macdonald clay loam soil (poorly drained, Dark Gray Gleysolic; pH 5.8–6.2) (Lajoie 1960). Previous crops in each location were wheat in 1996 and maize in 1995 on the Bearbrook clay site, and the Macdonald clay loam site. At the St Amable site, soybean was sown in 1996 and was in fallow in 1995. The single site in 1998 was located on a St Bernard loam soil (well drained, Melanic Brunisol, pH 6.0–7.0) (Lajoie 1960), and previous crops on this site were barley in 1997, and red clover in 1995 and 1996.

Land preparation in both years consisted of fall mould-board plowing followed by spring disking and harrowing prior to seeding. In both years, 200 kg ha⁻¹ of balanced inorganic fertilizer (20–10–10) (N–P₂O₅–K₂O) was broadcast and incorporated prior to seeding.

The fibre flax cultivar 'Ariane' was seeded at rates of 100 (1997) and 125 (1998) kg ha⁻¹ using a five row Bolens drill plot seeder having a row spacing of 20 cm, at manually controlled depths of 0, 1, 2, 4 and 6 cm, as measured in the field. Seeding occurred on 25 May in 1997 and 30 April in 1998 into 2 m × 5.5 m plots. The experimental design was a strip-plot in which the strips (vertical factor) comprised the seeding depth treatment, and the blocks (horizontal factor) comprised one of three seedbed preparation treatments: (i) rolling prior to seeding (RB), (ii) rolling after seeding (RA) or (iii) no rolling (NR). There were three blocks, with one replicate/treatment/block. The field layout in all sites in both years was identical.

High weed pressure necessitated herbicide application in both years. On 25 June 1997, the Bearbrook and St Amable clay sites were sprayed with bentazon (BASF Canada Inc., London, Ont., Canada) at a rate of 0.96 kg a.i. ha⁻¹ for the control of broadleaf weeds and yellow nutsedge (*Cyperus esculentus* L.). The Macdonald clay loam site was sprayed with sethoxydim (BASF Canada Inc.) + mineral oil surfactant (0.276 kg ai ha⁻¹ + 2 l ha⁻¹) for control of annual grasses. The 1998 site was sprayed on 29 May with fluzifop-*p*-butyl (Syngenta Crop Protection Inc., Guelph, Ont., Canada) + mineral oil surfactant (0.7 kg ai ha⁻¹ + 0.5 % v/v) for annual grass and quackgrass [*Elytrigia repens* (L.) Nevski] control. Bentazon was applied on 5 June (1.08 kg ai ha⁻¹) on this site to control emerged annual broadleaf weeds. All herbicide treatments followed recommendations for oilseed flax in Ontario (Anonymous 1997).

Data collection in both years included mean plant height per plot and was recorded approximately 9 weeks post-emergence. Height was determined by measuring plants from soil level to the uppermost growing point. The mean height per plot was the average of two observations in 1997 and six observations in 1998. At each of these sampling times, 8–12 plants were held together against a meter-stick, and their mean height estimated.

Plant densities in each plot were assessed 42 days after seeding (DAS) within four randomly placed 0.25-m² quadrats. The number of plants with branches on the lower 50 cm of stem was also recorded. A 'branching ratio' (Tratio) value was determined by dividing the number of plants with branches on the lower 50 cm of stem by the number of plants in each 0.25-m² quadrat. Stem diameters were measured in 1998 prior to harvest on 25 randomly selected plants per plot using a digital calliper (Marathon Electronics, Belleville, Ont., Canada) and plot mean values were used for data analysis.

'Retted' straw yield was also assessed in each plot. Plants within a 1-m² sub-plot were uprooted by hand when at least two thirds of leaves had senesced and capsules were turning brown (Stephens 1997). The soil was shaken from roots, plants were laid on the ground and left in the field for about 2 weeks, after which, they were turned over by hand, and left in the field for 10 additional days to complete the retting process. Retted plants in each plot were then collected and weighed. Due in part to the subjectivity involved in assessing the degree of retting for each treatment independently, fresh and dry weights rather were obtained in 1998 than retted weight. Dry weights were obtained by placing samples in a forced air electric drying unit at 65 °C for 48 h.

All data were subjected to analysis of variance (ANOVA) using the GLM procedure in SAS (SAS Institute Inc. 1985) to identify effects and interactions of seeding depth and seedbed preparation treatments. Treatment mean values were separated using the Tukey's HSD mean values comparison procedure at the P < 0.05 level of significance (Motulsky 1995). 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).

Results

1997 Field trials

The growing season in 1997 was much wetter than usual, with only June receiving normal precipitation. Temperatures were below average in April and May, and average for the rest of the season. The season-long number of growing degree-days (GDD) (base 5 °C) was 1828, 143 GDD lower than the 20-year average of 1971.

The effect of seedbed preparation (rolling) was not significant ($P \geq 0.05$) at the Bearbrook site. There was however, a significant ($P < 0.05$) effect of seeding depth on plant density. The 6-cm seeding depth treatment resulted in the highest plant densities (1348 plants m^{-2}), whereas the 0-cm seeding depth treatment resulted in the lowest plant densities (752 plants m^{-2}). There was a highly significant interaction ($P < 0.01$) between seeding depth and seedbed preparation on retted straw yield. The highest yielding treatment combination (6.1 t ha^{-1}) was sowing at a depth of 1 cm with no rolling, while sowing at a 0-cm depth and rolling prior to seeding resulted in no measurable yields (Table 1). The seeding depth and seedbed

preparation treatments had no effect on the branching ratio and height of flax plants.

Results from the St Amable site were similar to those obtained at the Bearbrook clay site in that there was no main effect of the seedbed preparation treatment on any of the parameters measured. However, seeding depth had a significant effect on plant density. The 1-cm sowing depth treatment resulted in the highest plant density (1089 plants m^{-2}) while sowing at a depth of 6 cm resulted in the lowest plant density (516 plants m^{-2}). There was a significant interaction ($P < 0.05$) between the seeding depth and seedbed preparation treatments on branching ratio and retted straw yield. The combination of the 0-cm seeding depth treatment and rolling prior to seeding produced the highest proportion (0.46) of branched plants (Table 2). The combination of the 1-cm seeding depth and rolling prior to seeding treatments yielded the most retted straw at 8.3 t ha^{-1} (Table 2). In contrast, the 4- and 6-cm sowing depth treatments that were rolled after seeding yielded only 3.0 and 2.7 t ha^{-1} of retted straw, respectively (Table 2).

Table 1: Comparison of fibre flax parameter mean values for all seeding depth-seedbed preparation treatment combinations at the Bearbrook clay site in 1997

Treatment	Plant density (m^{-2})	Branching ratio	Retted straw yield (t ha^{-1})	Height (cm)
Not rolled				
0 cm	476	0.28	2.2 cd	73.3
1 cm	1564	0.12	6.1 a	78.7
2 cm	1052	0.19	5.7 ab	79.7
4 cm	972	0.09	4.0 abc	71.7
6 cm	1636	0.10	5.3 ab	77.0
Rolled after				
0 cm	912	0.19	2.8 bcd	77.7
1 cm	1208	0.16	4.6 abc	77.0
2 cm	1124	0.10	5.6 ab	83.7
4 cm	1000	0.11	4.0 abc	78.7
6 cm	1104	0.12	4.6 abc	73.0
Rolled before				
0 cm	868	0.19	0 d	70.3
1 cm	1060	0.12	4.8 abc	74.3
2 cm	876	0.36	5.2 abc	74.7
4 cm	844	0.18	3.9 abc	73.3
6 cm	1304	0.12	5.3 ab	76.0
m.s.d.	—	—	3.1	—

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

NR, no rolling; RA, rolled after seeding; RB, rolled before seeding.
m.s.d., minimum significant difference.

Table 2: Comparison of fibre flax parameter mean values for all seeding depth-seedbed preparation treatment combinations for the St Amable sandy loam site in 1997

Treatment	Plant density (m ²)	Branching ratio	Retted straw yield (t ha ⁻¹)	Height (cm)
Not rolled				
0 cm	808	0.17 ab	5.7 ab	88.0
1 cm	852	0.15 ab	6.7 ab	90.7
2 cm	784	0.15 ab	5.8 ab	92.0
4 cm	656	0.03 b	5.8 ab	87.0
6 cm	712	0.13 ab	3.8 ab	89.7
Rolled after				
0 cm	1120	0.09 b	5.8 ab	87.7
1 cm	1008	0.21 ab	6.5 ab	92.0
2 cm	880	0.07 b	5.4 ab	92.0
4 cm	756	0.14 ab	3.0 b	88.7
6 cm	296	0.12 ab	2.7 b	86.7
Rolled before				
0 cm	880	0.46 a	4.2 ab	88.3
1 cm	1408	0.05 b	8.3 a	83.3
2 cm	1000	0.16 ab	7.5 ab	88.7
4 cm	852	0.09 b	6.1 ab	90.0
6 cm	540	0.25 ab	5.5 ab	87.0
m.s.d.	–	0.36	5.1	–

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

NR, no rolling; RA, rolled after seeding; RB, rolled before seeding.
m.s.d., minimum significant difference.

At the Macdonald clay loam site, there were significant ($P < 0.01$) interactions between seeding depth and seedbed preparation on plant height, branching ratio and retted straw yield. The tallest plants (81.0 cm) were found in the 4-cm sowing depth–non-rolled treatment combination plots, while the shortest plants (63.7 cm) were found in the 6-cm sowing depth plots rolled prior to seeding (Table 3). Plants with the highest branching ratio (0.62) were found in plots sown to a depth of 0 cm and rolled prior to seeding (Table 3). Plants did not differ significantly in branching ratio for any of the other treatment combinations. Sowing at a depth of 4 cm and rolling the soil prior to seeding resulted in the highest yield of retted straw (6.3 t ha⁻¹) while sowing at a depth of 0 cm and rolling the soil prior to seeding resulted in the lowest yield of retted straw (1.5 t ha⁻¹) (Table 3). Plant densities of flax were not affected by either the seeding depth or seedbed preparation treatments.

1998 Field trials

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 number of GDD (base 5 °C) was 2335, 364 GDD greater than the 20-year average of 1971.

There was a highly significant ($P < 0.01$) interaction between seeding depth and seedbed preparation on stem diameter and mean plant height 9 weeks following emergence. Stem diameters were greatest for plants in plots seeded at a depth of 6 cm and rolled after seeding and for plants in the 0-cm depth treatment rolled prior to seeding (Table 4). Stem diameters were lowest for plants in the 1- and 2-cm sowing depth plots rolled after seeding, and for the 2-cm sowing depth plots either rolled prior to seeding or not rolled at all (Table 4). Overall, plants within the 0-cm depth plots with no rolling were tallest (92.4 cm) while plants within the 2-cm depth treatment plots rolled prior to seeding were shortest (84.4 cm) (Table 4). Seeding depth and seedbed preparation treatments had no effect

Table 3: Comparison of fibre flax parameter mean values for all seeding depth-seedbed preparation treatment combinations for the Macdonald clay loam site in 1997

Treatment	Plant density (m ²)	Branching ratio	Retted straw yield (t ha ⁻¹)	Height (cm)
Not rolled				
0 cm	1348	0.14 b	5.7 a	75.0 abc
1 cm	888	0.25 b	5.7 a	75.0 abc
2 cm	1356	0.12 b	3.3 ab	78.3 ab
4 cm	1400	0.12 b	5.3 a	81.0 a
6 cm	1156	0.13 b	5.9 a	79.7 ab
Rolled after				
0 cm	1224	0.18 b	5.8 a	73.3 abcd
1 cm	1888	0.11 b	5.1 ab	67.3 cd
2 cm	1644	0.09 b	4.9 ab	72.7 abcd
4 cm	1556	0.23 b	4.6 ab	67.0 cd
6 cm	1828	0.19 b	4.6 ab	76.3 abc
Rolled before				
0 cm	920	0.62 a	1.5 b	72.0 abcd
1 cm	1624	0.17 b	5.4 ab	73.3 abcd
2 cm	2096	0.10 b	5.5 a	75.0 abc
4 cm	1556	0.15 b	6.3 a	70.3 bcd
6 cm	1468	0.07 b	6.2 a	63.7 d
m.s.d.	–	0.34	3.7	10.2

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

NR, no rolling; RA, rolled after seeding; RB, rolled before seeding.

m.s.d., minimum significant difference.

Table 4: Comparison of fibre flax parameter mean values for all sowing depth-seedbed preparation treatment combinations for the St Bernard loam soil site in 1998

Treatment	Stem diameter (mm)	Plant density (m ²)	Branching ratio	Height (cm)	Fresh yield (t ha ⁻¹)	Dry matter content (%)
Not rolled						
0 cm, NR	2.77 ab	1299	0.078	92.4 a	28.5	34.2
1 cm, NR	2.70 ab	1431	0.016	86.3 abc	30.8	33.3
2 cm, NR	2.42 b	1392	0.021	88.2 abc	30.3	34.5
4 cm, NR	2.74 ab	1478	0.026	85.8 bc	27.1	38.3
6 cm, NR	2.62 ab	1229	0.029	85.7 abc	24.0	38.7
Rolled after						
0 cm, RA	2.75 ab	1408	0.094	88.2 abc	32.8	34.8
1 cm, RA	2.44 b	1634	0.018	86.7 abc	28.8	37.3
2 cm, RA	2.42 b	1424	0.031	87.1 abc	24.2	35.3
4 cm, RA	2.74 ab	1525	0.049	86.4 abc	28.9	34.7
6 cm, RA	3.12 a	1516	0.067	88.3 abc	25.0	38.0
Rolled before						
0 cm, RB	3.10 a	1579	0.071	90.7 ab	26.5	35.2
1 cm, RB	2.51 ab	1540	0.078	86.6 abc	25.8	37.3
2 cm, RB	2.42 b	1376	0.080	84.4 c	26.1	37.2
4 cm, RB	2.59 ab	1525	0.072	88.9 abc	29.4	37.7
6 cm, RB	2.59 ab	1275	0.106	86.8 abc	29.4	37.0
m.s.d.	0.65	–	–	6.1	–	–

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

NR, no rolling; RA, rolled after seeding; RB, rolled before seeding.

m.s.d., minimum significant difference.

on flax planting density, branching ratio, and fresh and dry yield at this site.

Discussion

Seeding depth is considered to be a major determinant of crop establishment (O'Connor and Gusta 1994), and our results using fibre flax are consistent with this view. A seeding depth of 2 cm was suggested by Sultana (1983) to be optimal for fibre flax, while seeding depths > 4 cm can lead to substantially lower plant densities (Robert 1998). In our trials, a seeding depth of 2 cm generally resulted in average-to-above average fibre flax plant densities, mean heights and yields, and a lower proportion of branched plants. These plant features are considered important for fibre flax production where the fibres are destined for linen production (Hocking et al. 1987). Seeding depths of 1- and 4-cm also provided acceptable levels of establishment, growth and yield.

Seed-to-soil contact is essential in agricultural production systems where typically high levels of germination and emergence of crops is desirable (Lafond et al. 1996). However, findings in this study revealed no effect of seedbed preparation (i.e. rolling) on fibre flax growth and yield for any of the sites in either year, with the exception of plant height at the Macdonald clay loam site in 1997. In some instances, the seedbed preparation treatment did interact with seeding depth, but no clear trends emerged. Despite a lack of significant effects, rolling the plots after seeding generally resulted in greater fibre flax densities in lighter soils (e.g. St Amable site) compared with heavier soils (e.g. Bearbrook site). 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). In a Québec study, Robert (1998) observed beneficial effects of rolling field plots prior to seeding on fibre flax stand density and retted yields. Unfortunately, the Robert (1998) study did not include a rolling after seeding treatment with which to compare our results. Nonetheless, Robert (1998) did note that when the seedbed was too loose, actual seeding depths were greater than desired and resulted in lower seedling emergence levels than expected. Clearly, under these soil conditions rolling prior to seeding will be most beneficial.

In the 2 years of this study, stand densities never attained optimal levels of 1800–2000 plants m^{-2} . Increasing the seeding rate in 1998 by 25 kg ha^{-1}

was beneficial, but flax populations remained at densities nearly 25–30 % below optimal levels. Similarly, Robert (1998) and Couture et al. (2002) also experienced difficulties in achieving optimal population densities of fibre flax under Québec field conditions. In fact, Robert (1997) reported an average density of 900 plants m^{-2} at 35 farms growing fibre flax in Québec. Nonetheless, our flax stand densities appear to be well in line with those reported recently by Rossini and Casa (2003) in field trials in Italy. Although these workers reported that their target density was 2200 plants m^{-2} , they were only able to achieve stand densities at harvest of 1250–1850 plants m^{-2} in 2 of 3 years, and considerably lower densities in last year of the study. Thus, Rossini and Casa (2003) achieved harvest densities of approximately 70 % of the target seeding density, which compares favourably with the 71 % target seeding density achieved in our study. Similarly, Sankari (2000) in Finland reported flax densities of 536–699 plants m^{-2} based on a seeding rate of 800 seeds m^{-2} , for a final stand density of 74 % of the target density.

Although retted straw yields in 1997 appear excessively high relative to the plant densities achieved, exceptionally high rates of branching and increased plant stem diameters might account for this finding. Branching ratios were much reduced in 1998, likely because of the higher seeding rate and increased intra-specific competition amongst plants (Hocking et al. 1987). Contrary to findings by Rowland (1980), plant height in 1998 was not adversely affected by the generally greater plant densities obtained following increases in the seeding rate. In fact, mean plant height actually increased in 1998 compared with 1997.

In conclusion, the impact of seeding depth and seedbed preparation on fibre flax establishment, growth and yield may largely depend on soil type and the specific type of production system used. Our results demonstrate that the rolling of soil prior to seeding on lighter soils and at a seeding depth of 2 cm on most soils can be beneficial for fibre flax production under Québec growing conditions.

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References

- Anonymous, 1997: Ontario Guide to Weed Control 1998. Publication 75, Ontario Ministry of Agriculture, Food, and Rural Affairs. Queen's Printer (Ontario), Toronto.
- 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.
- 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.
- Hocking, P. J., P. J. Randall, and A. Pinkerton, 1987: Mineral nutrition of linseed and fiber flax. *Adv. Agron.* **41**, 221—290.
- 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., 1997: Rapport Annuel 1996 sur la Production de Lin Textile. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. Sainte-Martine.
- Robert, L., 1998: Rapport Final sur la Production de Lin Textile 1995–97. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. Sainte-Martine.
- Rossini, F., and R. Casa, 2003: Influence of sowing and harvest time on fibre flax (*Linum usitatissimum* L.) in the Mediterranean environment. *J. Agron. Crop Sci.* **189**, 191—196.
- Rowland, G. G., 1980: An agronomic evaluation of fibre flax in Saskatchewan. *Can. J. Plant Sci.* **60**, 55—59.
- Sankari, H. S., 2000: Linseed (*Linum usitatissimum* L.) cultivars and breeding lines as stem biomass producers. *J. Agron. Crop Sci.* **184**, 225—231.
- 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, CT.
- 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. Agricultural Development Fund Project no. 94000051, Saskatchewan.
- Wall, D. A., 1994: Response of flax and lentil to seeding rates, depths, and spring application of dinitroaniline herbicides. *Can. J. Plant Sci.* **74**, 875—882.