Flax Agronomy Research
Final Report

"Flax Growth and Development: Understanding Yield Formation and the Effects of Critical Stress Periods on Final Grain Yield."

1999 - 2002

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1.0 Introduction

One of the long term objectives of the flax industry, as indicated by the Flax Council of Canada in 1995, was to increase flax production to 5M acres by the year 2000. Although this target was not met, the goal still remains. The increased interest by consumers and the feed industry will contribute greatly to that demand and a steady supply must be ensured.

In the fall of 1995, a meeting was held among producers sitting on the Board of Directors of the Flax Council of Canada, other members of their Research and Development Committee and with researchers from across Manitoba and Saskatchewan. The end result was the approval of a project entitled: "Increasing Flax Yields: A closer look at fertilizer utilization and weed management." The funding approved for this three year project was $114,000 from Agriculture and Agri-Food Canada's Matching Investment Initiative; $90,000 for the Flax Council of Canada; $15,000 from Agrium and $12,000 from the Potash and Phosphate Institute of Canada for a total of $231,000. The flax research for this project was conducted at Melfort and Indian Head in Saskatchewan and at Morden and Brandon in Manitoba. In 1996, additional funding on the order of $100,000 was received from the Saskatchewan Agriculture Research Development Fund for a two year period to increase the number of sites in Saskatchewan by three, Swift Current, Scott and Canora. The total funding received was $100,000. The title of the project was "Enhancing Flax Production through Better Plant Nutrition.". The project has demonstrated clearly the needs of the flax crop in terms of nutrients and weed control. It is recommended that flax be fertilized to the same extent as canola.

On October 8, 1998, a meeting was held with flax researchers, the Flax Council of Canada and the Saskatchewan Flax Development Commission to discuss the results obtained on the above mentioned initiatives and to develop a set of research priorities for future agronomic research. The research priorities established were: 1) Understanding yield formation and yield components in flax and the effects of stress on overall productivity. 2) The effects of plant diseases like Fusarium wilt and powdery mildew on grain yield and the impact of the new seed treatments on overall plant heath and stand establishment 3) Understanding the relative performance of flax and canola in side by side comparisons to provide producers with a better understanding of the true potential of flax. 4) Aphid control in flax and what the critical economic thresholds are and 5) The critical weed free period in flax to avoid major yield losses from weed competition.

The research will provide direct economic benefits to the producers by giving them more options in terms of managing their flax for higher returns. Flax is also a crop that is fairly easy to manage. Better flax production also leads to a more vibrant flax industry with the usual economic spin-offs that result from this type of growth. Flax is a crop that has very few insect pests and plant diseases and therefore requires few pesticides which in turn is good for the environment.

2.0 Objectives

The objectives were to determine how flax grain yield is established, how agronomic factors affect the expression of grain yield and how environmental conditions during the various stages of plant development influence the expression of final grain yield. This can provide producers with more insight into the production potential of flax and tools to help them make better informed management decisions about the crop. The study also established the performance of flax relative to canola when an optimum management program is used. This was to demonstrate to producers the full potential of flax when the correct management program is used and highlight more explicitly some of the agronomic and economic benefits of flax relative to canola and how to manage them within the same cropping system.

3.0 Brief Description of Studies

3.1 Flax vs Canola

Plots were sown at total of four different locations; three in Saskatchewan, Melfort, Saskatoon, Indian Head and one in Manitoba, Brandon. The experimental design at all sites was a three factor split-plot design with three replicates. The main plot was crop (flax and canola) and the sub-plot was nitrogen fertilizer and seeding date. There were 16 plots in each replicate, for a total of 48 plots at each site. Trials were carried out in 1999, 2000 and 2001. The two seeding dates consisted of early May (week 1) and late May (last week). Four different N rates were used- 0, 67, 100, and 133% of the amount recommended for a target yield of 30 bu ac^{-1} for flax, and 35 bu ac^{-1} for canola, based on soil tests taken each spring prior to seeding. For other pertinent details about the trial, please refer to Appendix 8.1.

3.2 Yield Formation in Flax

Trials were carried out at 5 different locations in Saskatchewan and Manitoba- Indian Head, Melfort and Saskatoon, SK., and Brandon and Morden, MB. The experimental design was a four-factor factorial, randomized complete block design. There were 4 replicates with a total of 216 plots at Saskatoon, and 3 replicates with a total of 162 plots at each of the other locations. Three different varieties of flax (AC McDuff, CDC Valour, and Norlin) were sown at 3 different seeding rates, on 2 different dates, with 3 different fertilizer rates. The seeding rates were 22, 45 and 67 kg ha^{-1}. The seed weights were converted from kg ha^{-1} to seeds m^{-2}, which worked out to 400, 800 and 1200 seeds m^{-2}. The three different fertilizer treatments used were 67%, 100% and 133% of the nitrogen recommended for a target yield of 2020 kg ha^{-1} (30 bu ac^{-1}) flax, based on soil tests taken prior to seeding (0-15cm and 15-60cm depth). Details with regards to the pertinent agronomic information can be found in Appendix 8.2.

3.3. Flax diseases.

The plots looking at yield formation in flax were assessed twice at Brandon, Indian Head, Melfort and Saskatoon (pre-bloom and pre-maturity stages), and four times at Morden (seedling, pre-bloom, post bloom and pre-maturity stages) for disease incidence and severity in 2000 and 2001. In general, early assessments included data on early leaf infections by pasmo, yellowing, early powdery mildew and early lodging; while late assessments included late powdery mildew, pasmo on leaves and stems, and late lodging. There were no signs of Fusarium wilt or rust in these trials in both years of the study. The mean disease indices on a 1-9 scale were collected for all trials (1 means very low, and 9 is very high, except for vigor and stand where 1 was the best and 9 was the poorest). The area under the disease progress curve (AUDPC) was collected for pasmo only in the Morden trials. Data was analyzed using SAS.

3.3 Statistical Analysis

Data for both studies were analysed with the PROC MIXED procedure of SAS (Littel et al. 1996), with blocks as a random effect, and applied treatments as fixed effects. The analysis was conducted with sites (location by year combinations) as a random effect to make more general conclusions regarding the average influence of the treatments. In other words, inferences can be extended to all possible sites in the flax-growing region of Eastern Saskatchewan and Southwestern Manitoba with sites as a random effect. *P values for the site interactions indicate if and how much variability occurred for responses averaged across sites. An analysis with sites as a fixed effect was conducted to investigate interactions between site and treatment in detail—which sites were associated with the interactions.* Treatment effects were declared significant at $P < 0.05$ for all analyses. The results from these analyses will be presented in this report.

A multivariate analysis was conducted using a specialized form of principal components analysis, called multidimensional preference (MDPREF) analysis (Carroll 1972). The PRINQUAL procedure of SAS (SAS 1990) was used to perform the MDPREF analysis. This procedure is a generalized form of the standard principal components analysis. Mean estimates of responses for each applicable treatment combination were used as the data set for the analysis. The PRINQUAL procedure was implemented using an identity transformation followed by standardization to mean equals zero. Exploratory analysis indicated that the results of the first (x-axis) and second (y-axis) principal components contribute most to an understanding of responses to the treatments. The results of the MDPREF analysis were summarized in a biplot. Standardized principal component scores for each treatment combination were plotted as points in the ordination space. The eigenvectors (correlation between the transformed and original data) for the different response variables (or sites) were plotted as a point at the end of vectors projecting from the origin into various positions in the ordination space. Each vector was calculated as the hypotenuse of the right triangle formed by the angle associated with the eigenvectors for the two principal components. The absolute lengths of the vectors were multiplied by a factor of 2.25 to make more efficient use of the ordination space. The coincidence of vectors and treatment combinations in the same area of the ordination space suggested greater response levels for those treatment combinations. The results of these analyses will be used for the preparation of scientific manuscripts.

4.0 Flax vs Canola

A widely promoted crop rotation in Western Canada is a four-year rotation consisting of cereal - oilseed - cereal - pulse crop. The choice of crops within each phase of the rotation is numerous and will vary with agro-ecological zone. The most common oilseed crops will be mustard (oriental, brown or yellow) or canola for the drier areas of the prairies, such as the brown and dark brown soil zones. As a rule, very little flax is grown in these drier areas. As we move into the higher moisture areas of the prairies such as the thin-black, black and grey soil zones or especially the eastern prairies, flax and canola are often included in the same cropping system. However, for the shorter growing season areas of the thin-black, black and grey soil zones, we will find mostly canola and very little flax for reasons of crop maturity.

From an agronomic perspective, the question of interest to farm managers, is how do I maximize the opportunities or conversely minimize the risks associated with the inclusion of both flax and canola into a cropping system. This study attempts to shed light on this crop management dilemma by focussing on determining optimal nitrogen fertility and seeding date.

A summary of the analysis of variance for the variables of interest is provided in Table 4.1. Nitrogen, and to a lesser extend ($P = 0.07$) crop x nitrogen, were management practices that affected seed yields yield across all sites. The main effect of crop and all effects of seeding date did not affect yield. Total water use was not affected by the treatments when results were averaged across sites. Flowering variables (start and length) were affected by crop, seeding date or nitrogen when the results were averaged across sites, and generally the effect of nitrogen and seeding date differed between crops. Time to maturity was influenced by crop or seeding date, and not nitrogen, when results were averaged across sites. For all variables, site x crop x nitrogen/seeding date interactions were significant, or nearly so ($P < 0.07$), with the exception of flowering length where interactions with nitrogen did not occur and total water use where only differences between crops varied among sites.

Crop and seeding date effects are presented in Table 2. Generally, flax began flowering later than canola (average range of 4-7 days) and flowered for a shorter period than canola (average range of 2-4 days). Canola maturity was determined when 30% of pods on the main raceme showed changes in seed color from green to brown or black, which corresponds to swathing time. Flax maturity is determined when 75% of the bolls have turned brown. Maturity differences between the two crops ranged from 8-10 days longer for flax when calculated from date of seeding. When maturity was calculated from start of flowering, the average range in values was 1-6 days longer for flax than canola, again showing that canola still has a shorter time to maturity but less in absolute terms. However from a practical perspective, time to maturity calculated from seeding is the most meaningful from an agronomic perspective. This is why canola is the preferred oilseed crop for the shorter growing seasons in the thin-black and black soil zone. If a polish canola cultivar would have been used in this study, the maturity differences with flax would have been greater. With the variable total water use, values were similar between the two crops when results were averaged across sites. Because we are dealing with developmental variables in this case, we would expect interactions with sites for developmental variables because they are sensitive to temperature, heat units and water availability. We recognize heat unit differences between sites and because we are measuring this variable using calendar days rather than heat units, main effects and interactions with sites are highly probable and expected. A site x crop interaction for both total water use and yield corresponded with high-yielding situations (Figure 4.2 and 4.3) where total water use was greater for canola than for flax. Site x crop x seeding date interaction for yield reflects that risk associated with the assumption that seeding date consistently affects canola and flax yield.

Th overall effects due to crop and nitrogen fertilizer are presented in Table 4.3 and Figure 4.1. Nitrogen had a small effect on days from seeding to start of flowering in both crops. Nitrogen had no effect on canola flower duration but increased the flowering period by three days from the lowest to the highest nitrogen rate in flax. Nitrogen had a negligible effect on time to maturity in both crops when calculated from time of seeding. Total water use increased more with increasing rates of N in canola than flax. Water use efficiency increased with increasing rates of N in both crops, as would be expected due to the increase in yield with added nitrogen combined with only a small change in total water use. The response to added nitrogen was greater for canola than flax (Figure 4.1). The optimum N rate for canola was 136% of recommended and for flax 87% when calculated from a fitted quadratic equation. The fitted equations are the following:

Canola: Yield $= 1126 + 6.1(\text{N Rate}) - 0.02\,(\text{N Rate})^2$ R-squared = 0.99

Flax: Yield $= 1114 + 5.5(\text{N Rate}) - 0.03\,(\text{N Rate})^2$ R-squared = 0.99

The effects of locations, years and seeding date are presented graphically for canola in Figure 4.2 and for flax in Figure 4.3.

Some economic analyses were done to compare N returns between the two crops with N expenses removed in Figure 4.4 and 4.5 using the price and cost assumptions presented in Tables 4.5 and 4.6 and the data for the Figures 4.4 and 4.5 in Table 4.7. When N expenses are removed, the maximum economic rate for N fertilizer for canola is between 100 and 110% of N recommended and for flax 50% of recommended. Consequently for canola, when cost of nitrogen is included, the recommended rates are relatively close but that was not the case for flax.

Based on sites located at Melfort, Saskatoon, Indian Head and Brandon for the years 1999-2001, flax yielded on average 89% of canola on the first seeding date and 92% on the second seeding date. In an other unrelated study examining the effects of nitrogen rate, nitrogen form (urea vs anhydrous ammonia) and nitrogen placement (fall banding, side-banding, mid-row banding, spring broadcast) at Star City, Indian Head, Scott and Swift Current for the growing seasons 2000 and 2001 in side by side blocks of canola, flax and spring wheat, we observed that flax yielded 92% of canola when no N was added and 88% when recommended levels of N were used (Table 4.4). These results are the same to what we have observed in our present study.

Conclusions

For seeding date, it would appear that the yield depression is greater in canola than flax when planting is delayed and canola responds more to nitrogen than flax. The N recommendations for canola are appropriate based on the results from this study but could be lowered for flax. With flax, there does not appear to be benefits to using high rates of N to try and capture more economic yield. There may actually be merit for higher than recommended rates of N for canola. The risk would be much lower than in flax. Based on just these two observations, one would conclude that canola should be seeded first. Other considerations also need to be taken into account in determining whether to seed flax or canola first. In western Canada, herbicide tolerant canola accounts for the greater majority of seeded acres, whether they be Round-Up Ready, Liberty link or Smart canola types. This opens up a number of herbicide options. These canola cultivars provide weed control options that are not possible with flax. The benefits of early time of weed removal has been well demonstrated in canola but is not possible with flax. Most registered broadleaf weed herbicides in flax cannot be sprayed before the crop is a minimum of 2" high. Consequently, it also makes more sense to seed canola first from a weed management perspective. Seeding canola earlier also means more efficient use of early season soil moisture, better nitrogen use efficiency, and flowering will occur earlier in the growing season avoiding the higher temperatures that can be experienced with later seeding dates. It is important to note that although canola should be seeded first, flax has a longer time to maturity than canola so producers need to be careful not to seed their flax too late. The earlier maturity of canola combined with early seeding creates an ideal situation for seeding winter wheat.

The results of this study provides some insight on how a producer should manage flax and canola within the same cropping system. We are assuming that the preferred choice or best crop management approach would be to seed canola and flax on cereal stubble. We also recognize that with the current crop management tools available, earlier seeding tends to be the preferred option. Data from the Manitoba Crop Insurance database supports this premise for most crops unless sensitivity to early spring frost or cool temperatures is a big issue as would be the case for crops like corn, sunflower and dry bean. We are also recognize that the farm manager cannot seed all his crops in the first week of May, which would be the optimum time for planting in many parts of the current flax and canola growing areas of Saskatchewan and therefore has to make decisions on the order with which he will seed his crop. The information provided is between flax and canola. The rules on order of planting will need to be expanded as cereal and pulse crops are also included in the rotation in order to balance opportunities with risks associated with delayed seeding. Consequently, based on the results of this study and given the assumptions above, canola should be seeded before flax.

Another important observation is the average yield recorded over the twelve site years for the two crops in question, given that the locations are very representative of the area of the eastern prairies where both canola and flax are commonly grown together on the same farm. Canola averaged 1405 kg/ha (25.3 bus/acre) and flax 1274 kg/ha (20.4 bus/acre). Given the reported yields and the associated costs for growing those crops, a number of interesting questions comes to mind:

- Are those average yields economically sustainable?

-How have improvements in overall crop management technology over the last 15 years helped to improve the economic returns at the farm gate with canola and flax?

-How do the overall production economics of flax and canola really compare?

-Should we be focussing more of our attention on how to reduce production costs rather than trying to increase yield? There is more risk in trying to increase yield than by trying to reduce costs.

Table 4.1. Analysis of variance combined over years and location. Each year and location combination consists of a site which was then used in the analysis.

Effect	Flower start	Flower duration	Maturity	Total water use	Soil water use	Water use efficiency	Yield
				(*P* value)			
Crop (C)	**< 0.001**	**0.021**	**0.012**	0.613	0.450	0.259	0.356
Seeding date (D)	**0.010**	**0.016**	**0.028**	0.133	0.691	0.370	0.520
C x D	**0.009**	0.424	0.618	0.875	0.989	0.660	0.713
N fertilizer rate (N)	0.067	**<0.001**	0.269	0.494	0.489	**0.017**	**0.004**
C x N	**0.009**	**0.010**	0.866	0.540	0.542	0.574	0.072
N x D	0.585	0.790	0.348	0.663	0.657	0.925	0.383
C x N x D	0.610	0.203	0.492	0.688	0.625	0.594	0.633
Site (S)	**0.032**	0.185	0.083	**0.019**	**0.026**	**0.033**	0.093
S x C	0.161	**0.033**	**0.035**	**0.030**	**0.027**	**0.050**	**0.056**
S x N	0.483	0.253	0.107	0.096	0.093	0.317	**0.009**
S x C x N	**0.043**	0.323	0.067	0.181	0.178	0.022	0.062
S x D	0.439	**0.016**	**0.038**	0.170	0.084	0.423	—
S x C x D	**0.017**	**0.023**	**0.031**	0.099	0.133	**0.029**	**0.006**
S x N x D	0.128	0.446	—	0.379	0.386	—	0.095
S x C x N x D	—*	—	0.082	—	—	—	—

* Variance estimate is near to 0. Therefore, the interactions are not important.

Table 4.2. The effects of crop and seeding date on various agronomic variables measured.

Crop / Seeding date	Flower start	Flower duration	Maturity	Total water use	Soil water use	Water use efficiency	Yield
	(DAS)	(days)	(DAS)	(cm)		($kg\ ha^{-1}\ cm^{-1}$)	($kg\ ha^{-1}$)
Canola							
Early	53	24	102	27.5	7.0	56	1441
Late	48	21	91	26.5	7.3	61	1368
Flax							
Early	60	20	110	27.0	6.1	48	1284
Late	52	19	101	25.9	6.4	50	1263
$LSD_{0.05}$	**5**	**2**	**8**	**1.6**	**1.7**	**12**	**209**

Table 4.3. The effects of crop and nitrogen rate on various agronomic variables measured.

Crop / N Fertilizer rate*	Flower start	Flower duration	Maturity	Total Water Use	Soil Water Use	Water Use Efficiency
	(DAS)**	(days)	(DAS)	—— (cm)	——	(kg ha^{-1} cm^{-1})
Canola						
0	50	22	96	26.1	6.2	51
67	50	23	97	27.2	7.3	62
100	51	22	97	27.2	7.3	59
133	51	23	97	27.6	7.7	62
Flax						
0	56	18	105	26.2	6.0	45
67	56	19	105	26.7	6.5	52
100	56	20	105	26.4	6.2	51
133	56	21	106	26.5	6.3	48
$LSD_{0.05}$	**1**	**1**	**2**	**1.5**	**1.5**	**8**

*** Percentage of recommended rate.**
**** DAS refers to days after seeding.**

Table 4.4. Comparison of the yield (kg/ha) of flax vs canola for other research trials at four locations and two years in Saskatchewan.

Location	Year	No Nitrogen		Recommended Nitrogen[1]	
		Flax	Canola	Flax	Canola
Star City	**2000**	1632	1889	1801	2354
	2001	1060	430	1130	693
Indian Head	**2000**	1421	2303	1558	2277
	2001	1050	1020	1105	1443
Scott	**2000**	1087	637	1983	1089
	2001	960	680	1200	775
Swift Current	**2000**	1594	2744	1689	3291
	2001	600	420	750	700
	Mean	1176	1265	1402	1578

[1] The N rate used at Star City and Indian Head was 80 kg-N/ha and at Scott and Swift Current 60 kg- N/ha. Each value represents the mean of 16 observations.

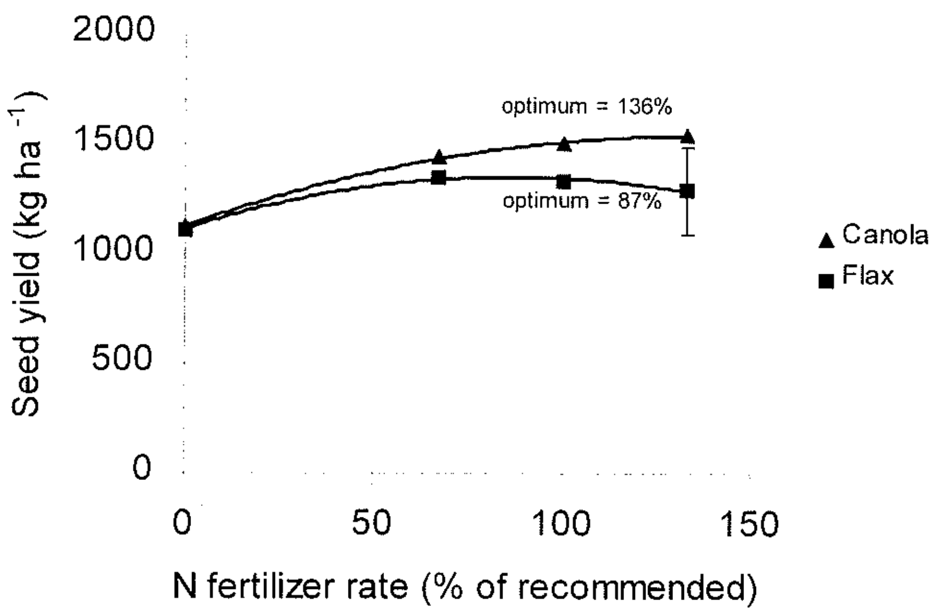

Figure 4.1. The effects of nitrogen fertilizer on the yield of flax and canola.

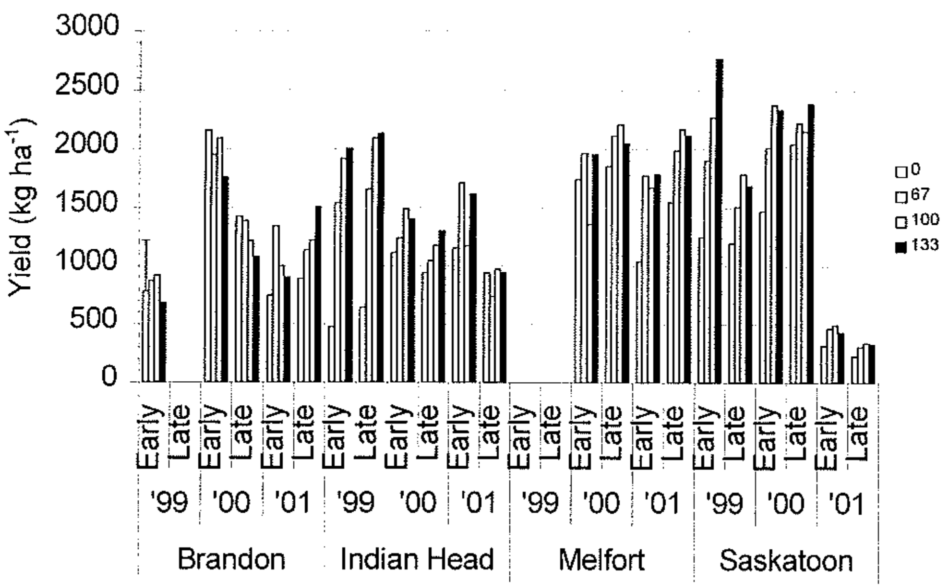

Figure 4.2. Canola yield responses. Error bar represents $LSD_{0.05}$ for site x crop x seeding date x N fertilizer rate interaction means.

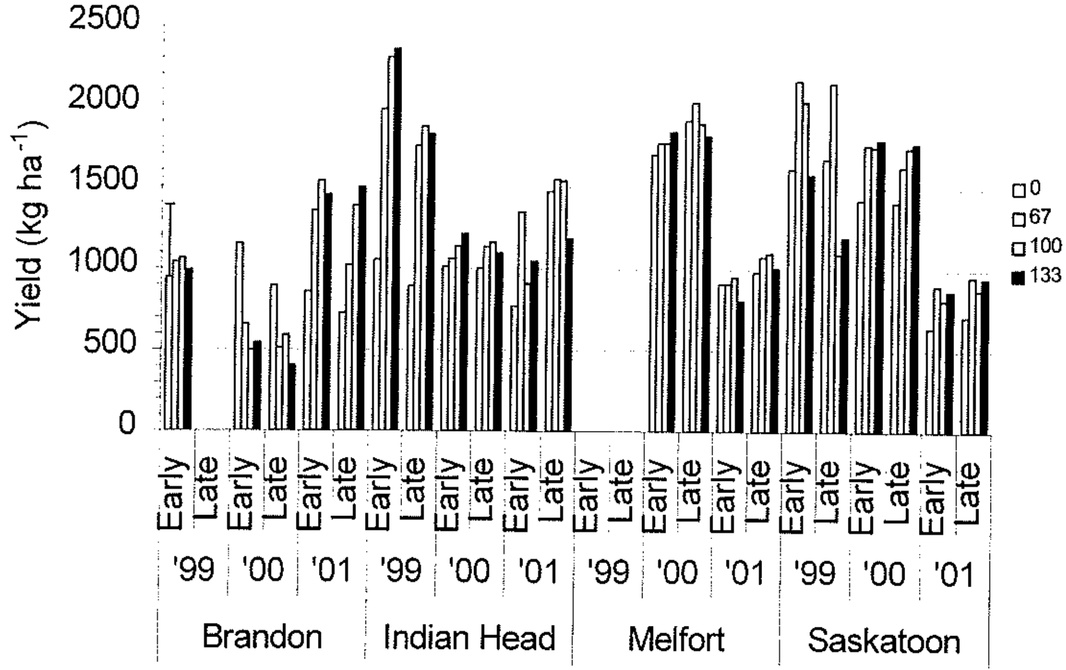

Figure 4.3. Flax yield responses. Error bar represents $LSD_{0.05}$ for site x crop x seeding date x N fertilizer rate interaction means.

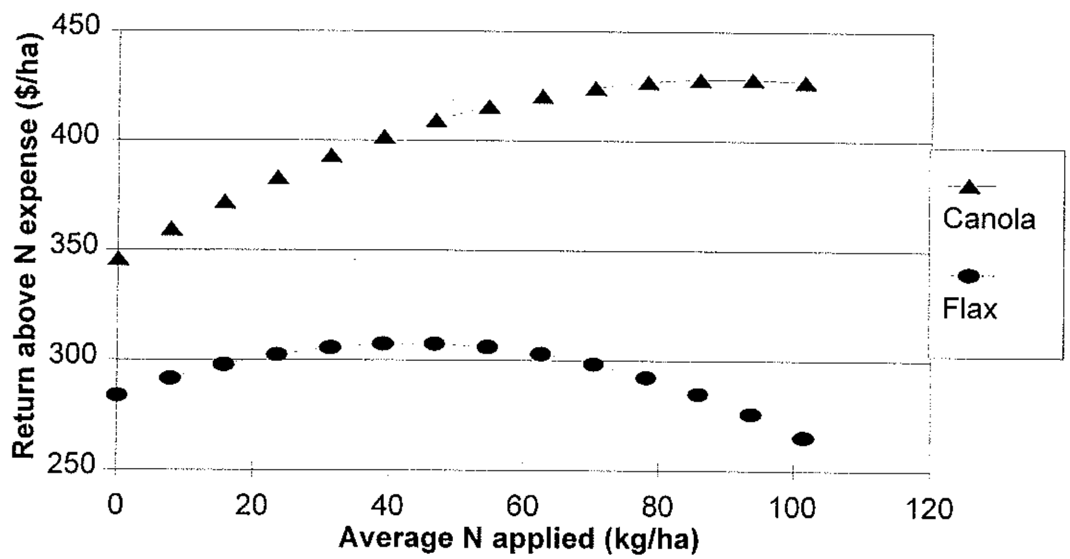

Figure 4.4. The effects of nitrogen rates on the net returns above N expenses for canola and flax.

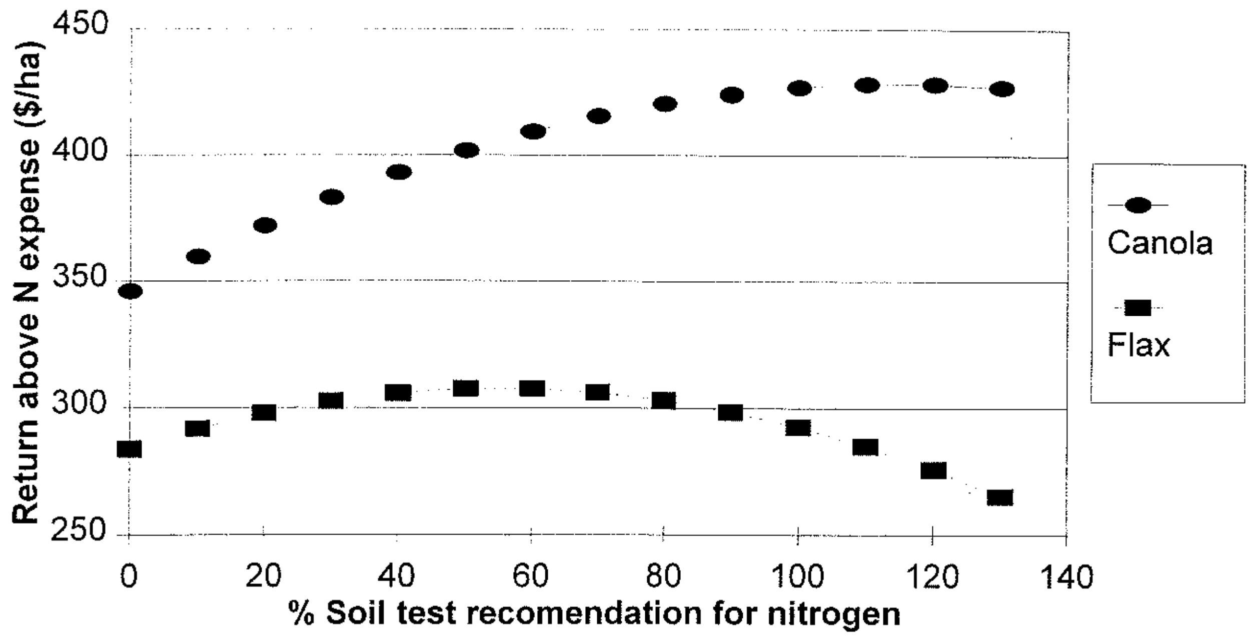

Figure 4.5. The effect of different N levels as a % of recommended on the net returns after N expenses of flax and canola.

Table 4.5. Fertilizer and commodity prices used for economic analysis.

Long Term Commodity Prices[1]					
	$/tonnes		$/bushel		$/tonnes[2]
Year	Flax	Canola	Flax	Canola	Urea
89/90	341.0	264.0	8.7	6.0	256.0
90/91	188.0	251.0	4.8	5.7	235.0
91/92	149.0	234.0	3.8	5.3	235.0
92/93	206.0	254.0	5.2	5.8	235.0
93/94	217.0	302.0	5.5	6.8	248.0
94/95	261.0	348.0	6.6	7.9	245.0
95/96	294.0	366.0	7.5	8.3	382.0
96/97	324.0	393.0	8.2	8.9	388.0
97/98	333.0	379.0	8.5	8.6	354.0
98/99	292.0	346.0	7.4	7.8	282.0
99/00	200.0	246.0	5.1	5.6	262.0
Average	**255.0**	**307.5**	**6.5**	**7.0**	**283.8**
High	341.0	393.0	8.7	8.9	388.0
Low	149.0	234.0	3.8	5.3	235.0
SD	66.2	60.1	1.7	1.4	60.5

[1] Based on data received from Saskatchewan Agriculture and Food
[2] Based on survey data obtained from Manitoba Agriculture (Source: John Heard)

Table 4.6. Actual amount of nitrogen used (kg/ha) for each year and location at the 100% recommended rate.

		Location				
Year	**Flax**	**Brandon**	**Indian Head**	**Saskatoon**	**Melfort**	**Average**
1999		130	101	60	50	85.25
2000		60	110	62	50	70.5
2001		90	101	73	50	78.5
Average		**93**	**104**	**65**	**50**	**78**
	Canola					
1999		130	101	100	85	104
2000		60	130	84	85	90
2001		90	123	75	80	92
Average		**93**	**118**	**86**	**83**	**95**

Table 4.7. Summary of calculations used for generating yield response curve and economic analysis as a function of nitrogen rate.

		% of Nitrogen Recommended													
		0	10	20	30	40	50	60	70	80	90	100	110	120	130
Yield (kg/ha)	Canola	1126	1185	1240	1291	1338	1381	1420	1455	1486	1513	1536	1555	1570	1581
	Flax	1114	1166	1212	1252	1286	1314	1336	1352	1362	1366	1364	1356	1342	1322
Cost of N Fertilizer ($/ha)[1]	Canola	0.00	5.52	11.05	16.57	22.10	27.62	33.15	38.67	44.20	49.72	55.25	60.77	66.29	71.82
	Flax	0.00	4.53	9.06	13.59	18.12	22.64	27.17	31.70	36.23	40.76	45.29	49.82	54.35	58.87
Gross Return ($/ha)[2]	Canola	346.25	364.39	381.30	396.98	411.44	424.66	436.65	447.41	456.95	465.25	472.32	478.16	482.78	486.16
	Flax	284.07	297.33	309.06	319.26	327.93	335.07	340.68	344.76	347.31	348.33	347.82	345.78	342.21	337.11
Net Return ($/ha)	Canola	346.25	359.86	372.24	383.40	393.32	402.01	409.48	415.71	420.71	424.49	427.03	428.35	428.43	427.28
	Flax	284.07	291.81	298.01	302.69	305.83	307.45	307.53	306.09	303.11	298.61	292.58	285.01	275.92	265.29
Actual N Applied (kg/ha)	Canola	0.00	9.53	19.05	28.58	38.10	47.63	57.15	66.68	76.20	85.73	95.25	104.78	114.30	123.83
	Flax	0.00	7.81	15.62	23.43	31.23	39.04	46.85	54.66	62.47	70.28	78.08	85.89	93.70	101.51
Less 10% opportunity cost for N fertilizer	Canola	346.25	359.41	371.34	382.04	391.51	399.75	406.76	412.54	417.09	420.41	422.50	423.36	422.99	421.40
	Flax	284.07	291.25	296.91	301.03	303.62	304.69	304.22	302.22	298.69	293.64	287.05	278.93	269.29	258.11

[1] Fertilizer was costed at $0.61/kg of urea N. Refer to Table 4.4 for determination of fertilizer costs.
[2] Commodity prices were determined from data presented in Table 4.5.

5.0 Yield Formation in Flax.

The objective of the study was to quantify the effects of various agronomic factors (cultivar, seeding date, seeding rate, nitrogen rate and location) on yield formation in flax. These agronomic factors were deemed to have the largest effect on yield based on a number of previous studies. A greater knowledge of yield formation in flax should lead to a better understanding of the management practises to obtain consistent yields and also provide some potential selection strategies for plant breeding programs. The nature of the statistical analysis is provided in Section 3.3. A summary of the analysis of variance for all the variables collected is provided in Table 5.1 along with the respective probability values for all effects measured. A summary of the main effects is provided in Table 5.2.

Better plant stands were obtained with the later seeding date (Table 5.2 and Figure 5.1) regardless of cultivar. As expected the plant populations increased with increasing seeding rates. It should be noted that even at the high seeding rates, the plant populations were only in the upper range of the recommended plant populations of 300-400 plants per meter square. One has to wonder if higher seeding rates shouldn't be recommended than the current seeding rate 45 lbs/acre to 56 lbs/acre. Emphasis should be placed on encouraging producers to use higher seeding rates because of the beneficial effects on maturity and better competition against weeds and also the larger number of bolls per unit area produced which, as will be discussed later, is the yield component that appears to have the largest influence on final seed yield. Increasing the current seeding rate recommendations by 20% would still not represent a large added cost due to the low cost for flax seed.

The effects of agronomic factors were also quantified for days required from seeding to 10% flowering, from 10% flowering to 90% flowering and from seeding to maturity. This was to determine how the maturity differences are expressed between the various cultivars and how seeding rates and nitrogen rate influence those as well. CDC Valour tended to flower earlier than the other cultivars. Nitrogen and seeding rate had no important effects on those variables (Table 5.2 and Figure 5.2). In terms of flower duration, the effects observed from the agronomic factors in question were negligible. Time to maturity was definitely lowest for CDC Valour, as expected. It is interesting to note that most of the differences in maturity between cultivars occur after the flowering has ceased ie. end of flowering to maturity (Table 5.2). From a crop management perspective, it is important to note that when nitrogen is applied at the recommended rate, maturity is not affected. Increasing the seeding rate from 22 to 45 kg/ha reduced maturity time on average by one day. Consequently in situations of delayed seeding, producers should not be concerned about lowering their N rates for fear of significantly increasing the time required for the crop to mature. These results also show that measuring the time required for the plots to reach the stage where 75% of the bolls have turned brown is a good method for estimating maturity.

The question foremost in the minds of agrologists and producers is how those agronomic factors influence seed yield and which interactions need to be noted. Of interest is the fact that the main effects cultivar, seeding date and nitrogen rate had no effect on grain yield (Table 5.2). However a number of interactions were observed to help explain the lack of main effect from some of those main agronomic factors. A large number of interactions were observed with site, as to be expected (Table 5.1). Increases in seeding rate showed a small but consistent increase in grain yield (Table 5.2). The seeding date x nitrogen rate interaction was such that an N response was only observed on the first seeding date (Figure 5.3). The cultivar x nitrogen x seeding rate interaction was due mainly to the effect of the cultivar Norlin (Figure 5.4). With CDC Valour and AC McDuff, there was a strong seeding rate response and the nitrogen response was more pronounced at the lowest seeding rate while at the other two seeding rates, the effect of nitrogen was not consistent. Norlin showed a different pattern of response. A response to nitrogen only occurred at the intermediate and highest seeding rate. The interactions with site-year for seed yield are given in Figures 5.11, 5.12 and 5.13.

Some important observations need to be noted. The choice of cultivar combined with seeding rate interacted with nitrogen. With AC McDuff and CDC Valour, the response to N decreased as seeding rate increased but the opposite was observed with Norlin. The seeding rate response was greater for AC McDuff and CDC Valour than for Norlin. There was a wider range of treatments that provided optimal yield for AC McDuff, whereas only a couple of the treatments maximized yield for the other cultivars (Figures 5.11, 5.12 and 5.13). This reinforces the notion that agronomy research should always be closely linked to plant breeding programs. With the recent introduction of high yielding cultivars like CDC Bethune and Taurus, agronomy research is required to exploit this newly found genetic potential.

Boll production, expressed on a per plant basis, was greatest for AC McDuff and CDC Valour (Table 5.2). However this may be due to the fact that more plants were established with Norlin. Increasing seeding rate to the recommended or greater than recommended rates decreased boll production as a result of more interplant competition while the addition of nitrogen fertilizer increased the number of bolls produced per plant. More bolls per plant were observed on the first seeding date and the response to nitrogen was also greater on the first seeding date (Figure 5.5). From a crop production perspective, the important component is not just bolls per plant but bolls per unit area which is a function of bolls per plant and plants per unit area. This component was most influenced by nitrogen fertilizer even though the response was different between the early and late seeding date (Figure 5.6).

Another important yield component is the number of seeds per boll. Seeds per boll was greatest for CDC Valour on both seeding dates (Figure 5.7). Seeding rate had varied effects on seed per boll but when averaged across all other factors, an increase in seeding rate tended to decrease seeds per boll. Nitrogen and seeding date had no effect. Variations in this average effect for seeding rate tended to be most notable for late seeded AC McDuff (cultivar x seeding date x seeding rate), and for late seeded flax at the two highest N fertilizer rates (seeding date x nitrogen rate x seeding rate).

Seed weight was greatest for CDC Valour and NorLin and the early seeding date. Increasing N fertilizer rate decreased seed weight for AC McDuff and NorLin at the latest seeding date (cultivar x seeding date x nitrogen rate) (Figure 5.8). Seeding rates greater than the recommended rate decreased seed weight when averaged across all other factors (Table 5.2). However, the effect of seeding rate tended to vary among the different combinations of cultivar and N fertilizer rate as indicated by the cultivar x nitrogen rate x seeding rate. In general, early seeding and lower seeding rates provide the greatest likelihood of maximizing seed weight.

The main attributes of flax seed is its oil content and composition. Oil concentration was greatest for AC McDuff (Figure 5.9). N fertilizer rate did not affect oil concentration. A decrease in oil concentration due to seeding date was observed for CDC Valour and to a much lesser extent Norlin (Figure 5.9). Seeding rates greater than the recommended rate decreased oil concentration at the highest N fertilizer rates (N x R). The effects in absolute terms were small.

Also, the effect of seeding rate was most notable for late seeded AC McDuff as indicated by the cultivar x seeding date x seeding rate interaction. The effects were small. In general, the most effective tool to optimize oil concentration was cultivar choice (AC McDuff) and N fertilizer rate.

In order to determine which yield component was the most responsive in terms of influencing final grain yield and in turn which agronomic practise had the largest effect on that component, a path analysis was conducted using the variables seed yield, the three yield components (seeds per boll, seed weight and bolls per unit area) and selected climatic data for each treatment by block by site combination using all the data collected. The model described relationships and causation among these variables (see Figure 5.10). Path coefficients, which are the standardized regression coefficients (Dewey and Lu 1959) [Dewey, D. R., and Lu, K.H. 1959. A correlation and path-coefficient analysis of components of crested wheatgrass seed production. Agron. J. 51: 515–518.], were estimated for each variable combination using the PROC REG procedure of SAS. The following sets of equations were simultaneously solved to estimate the path coefficients:

Yield = bolls m^{-2} + seeds $boll^{-1}$ + seed weight
Bolls m^{-2} = flowering period
Seeds $boll^{-1}$ = bolls m^{-2} + vegetative period + seed filling period + 25–30°C period + >30°C period
Seed weight = bolls m^{-2} + seeds $boll^{-1}$ + seed filling period
Seed filling period = bolls m^{-2} + vegetative period + GDD seed filling period
Vegetative period = GDD vegetative period
Flowering period = vegetative period + 25–30°C period + >30°C period + GDD flowering period

A summary of the path coefficient analysis is presented in Figure 5.10. Boll production (bolls m^{-2}) was clearly the most important yield component associated with flax yield. Variations for seeds $boll^{-1}$, and to a lesser extent seed weight, were not as important in determining final grain yield. Growing degree days from the start to the end of flowering via effects on flowering period and then bolls m^{-2} was the most influential combination of crop/environmental factors dictating yield variations or explaining final seed yield. Effects of excessive temperatures during flowering on yield via the path flowering period then boll m^{-2} then yield was not as influential as GDD during flowering. However, temperatures of 25–30°C via seeds $boll^{-1}$ was a path of intermediate importance affecting flax yield formation. Factors associated with the duration of the vegetative period prior to the start of flowering were not related strongly with final seed yield. However no specific measurements were done during that period other than plant counts. The effects of timing of the herbicide applications on final seed yield needs to be documented. Growing degree days from the end of flowering to maturity was strongly associated with length of the seed filling period and consequently seed weight. However, the ultimate effect of GDD late in the growing season was small because of the lesser importance of seed weight as a yield formation factor. The number of days with maximum daily temperatures between 25 and 30 degrees C and greater than 30 degrees C during the flowering period is provided in Figure 5.15.

Another component of the study involved calculating growing degree days (base temperature of 0 degrees C) for different growth periods. The growth periods in question were seeding to 10% flowering, 10% flowering to 90% flowering and from seeding to maturity. The intent was to determine if this may be a good way to the identify the latest seeding date permissible for different agro-ecological zones of western Canada as a function of growing degree days required to reach maturity and how that compares with the calendar day for the first fall frost. A summary of the results for seeding date and cultivar is given in Figure 5.14. Based on the locations used in the study and the number of years, it is very apparent that using growing degree days to estimate maturity is very plausible. Also maps could easily be developed for western Canada to determine the latest permissible seeding date. With some minor corrections, maturity could easily be predicted as well.

Conclusions: The main interest in this study was to examine closely how yield formation in flax is influenced by some of the more important agronomic factors. Given the large number of factors included in the study, there was also interest in determining any interactions between factors that could be of agronomic interest. An example was the seeding date x nitrogen rate interaction where the nitrogen rate response disappeared at the later seeding date. Other important interactions were discussed and their agronomic importance noted. It is interesting to note that overall, the three cultivars performed the same, on average, despite site x cultivar interactions for grain yield.

The yield component with the largest influence on yield was bolls per unit area. Further research is required in order to determine how agronomic practises can be influenced to encourage boll production.

Information from other field studies in Saskatoon measuring quantitative characters in flax, based on material from Canada and the world collection reveals a large amount of genetic variability for the yield components seeds per boll and seed weight (Table 5.3). There also exists good variability in time to maturity and time to start of flowering. There exists an opportunity to develop parental material that brings together some of those attributes and introgressing these characters into some of our current varieties.

If we are to have an impact on further increasing seed yield in flax, we need to evaluate a wider range of varieties in terms on varying attributes using a rigorous agronomy field program. An example would be to evaluate late maturing, high yield flax lines across the flax growing areas of the eastern prairies and varying the crop management approach to fully exploit the genetic potential without disproportionately increasing the cropping risk.

More work is required on yield formation, using some of our more recent cultivars under a range of growing conditions to learn more about how environmental conditions influence seed yield in flax.

Table 5.1. Analysis of variance of all variables collected during the three year study.

Effect	Plant density	Flower start	Flower duration	Maturity	Yield	Bolls $plant^{-1}$	Bolls m^{-2}	Seeds per boll	Seed weight	Oil conc.
	(*P* value)									
Cultivar (C)	**0.002**	**< 0.001**	**< 0.001**	**< 0.001**	0.988	**0.012**	0.153	**0.021**	**0.009**	**0.002**
Seeding date (D)	**0.025**	**< 0.001**	0.132	**< 0.001**	0.710	0.075	0.379	0.171	**0.003**	**0.025**
C x D	0.522	**0.028**	0.552	0.156	0.703	0.497	0.485	0.978	0.397	0.522
N fertilizer rate (N)	0.335	0.963	**< 0.001**	0.573	0.122	**0.002**	**0.002**	0.906	**0.009**	0.335
C x N	0.462	0.862	0.256	0.900	0.548	0.188	0.563	0.419	0.073	0.462
D x N	0.435	0.951	0.129	0.517	**0.006**	**0.015**	0.068	0.501	0.890	0.435
C x D x N	0.680	0.562	0.487	0.465	0.587	0.389	0.801	0.294	**0.034**	0.680
Seeding rate (R)	**< 0.001**	**< 0.001**	**< 0.001**	0.440	**0.001**	**< 0.001**	0.091	**0.042**	**0.001**	**< 0.001**
C x R	**0.033**	0.533	0.340	0.287	**0.002**	0.382	0.939	0.059	0.124	**0.033**
D x R	0.157	0.935	0.603	0.277	0.818	0.580	0.526	0.309	0.551	0.157
N x R	0.648	0.577	0.269	0.778	0.975	0.635	0.730	0.517	0.235	0.648
C x D x R	0.065	0.599	0.511	0.348	0.750	0.534	0.379	**0.053**	0.589	0.065
C x N x R	0.998	0.309	0.926	0.370	0.062	0.213	0.828	0.189	**0.047**	0.998
D x N x R	0.763	0.857	0.640	0.079	0.686	**0.006**	0.898	0.106	0.764	0.763
C x D x N x R	0.376	0.167	0.607	0.776	0.208	0.473	0.506	0.515	0.099	0.376
Site (S)	**0.030**	**0.020**	**0.013**	**0.009**	**0.008**	**0.017**	**0.008**	**0.021**	**0.007**	**0.030**
S x C	**0.006**	**0.002**	—[z]	—	**0.007**	**0.003**	**0.014**	**0.003**	**< 0.001**	**0.006**
S x D	**0.011**	**0.006**	**0.013**	0.113	**0.007**	**0.023**	**0.008**	**0.020**	**0.012**	**0.011**
S x C x D	**0.011**	**< 0.001**	**< 0.001**	**< 0.001**	**0.004**	**0.054**	0.084	0.490	**0.002**	**0.011**
S x N	—	—	0.142	—	**0.015**	0.410	0.303	—	**0.032**	—
S x C x N	—	—	—	—	—	0.183	—	—	0.367	—
S x D x N	0.125	—	0.106	—	0.102	0.053	0.318	0.153	—	0.125
S x R	**0.003**	0.139	0.211	—	**0.054**	**0.003**	**0.011**	0.253	**0.025**	**0.003**
S x C x R	**0.003**	0.254	—	**< 0.001**	0.211	0.143	0.350	0.393	—	**0.003**
S x D x R	**0.004**	—	**0.021**	**< 0.001**	**0.024**	0.083	—	0.427	0.197	**0.004**
S x N x R	0.112	—	0.493	—	—	0.124	0.437	—	—	0.112

[z] Variance estimate is '0'.

Table 5. 2. Summary of main effects for the variables collected during the study.

Effect / Level	Plant density	Flower start	Flower duration	Maturity	Yield	Bolls #		Seed #	Seed weight
	(no. m^{-2})	(DAS)	(days)	(DAS)	(kg ha^{-1})	($plant^{-1}$)	(m^{-2})	($boll^{-1}$)	(mg)
Cultivar									
AC McDuff	302	57	18	107	1426	19.9	4629	7.25	5.48
CDC Valour	304	54	20	101	1428	19.2	4486	7.44	5.76
NorLin	359	55	20	103	1422	16.2	4681	7.14	5.67
$LSD_{0.05}$	**33**	**1.4**	**0.8**	**3**	**78**	**2.5**	**207**	**0.21**	**0.18**
Seeding date									
Early	291	59	20	108	1439	19.6	4517	7.37	5.73
Late	353	52	19	99	1411	17.2	4680	7.19	5.54
$LSD_{0.05}$	**53**	**2.3**	**1.9**	**4**	**159**	**2.6**	**386**	**0.27**	**0.11**
N fertilizer rate (% of recommended)									
67	327	55	19	103	1400	16.9	4472	7.28	5.67
100	318	56	19	103	1429	19.0	4646	7.28	5.63
133	321	55	20	104	1446	19.3	4677	7.27	5.61
$LSD_{0.05}$	**12**	**0.1**	**0.4**	**1**	**46**	**1.3**	**116**	**0.08**	**0.03**
Seeding rate									
22	199	56	20	104	1368	25.9	4492	7.34	5.67
45	329	55	19	103	1445	16.6	4625	7.27	5.65
67	437	55	19	103	1462	12.7	4678	7.22	5.59
$LSD_{0.05}$	**41**	**0.2**	**0.4**	**2**	**48**	**2.4**	**172**	**0.09**	**0.04**
					(%)				
cv	62	13	28	17	43	75	36	14	14

Table 5.3. Ranges of diversity for selected quantitative characters in flax

Character	n	min.	$x_{0.5}$	max.	cv (%)
Days emergence-maturity	2782	67	92	112	6.24
Petal width (mm)	2442	3.04	9.67	15.82	17.49
Seeds per capsule (Number)	2098	5.1	8.80	10.60	12.31
Plant height (cm)	2746	20	62	130	24.61
Weight of 1000 seeds (g)	2670	2.83	5.87	11.50	20.6
Oil content in seeds (%)	2672	26.19	38.31	45.63	4.61
α-linolenic acid (%)	2243	39.59	52.61	66.71	7.51

n=number of accessions; min.=minimum; $x_{0.5}$=median; max.=maximum; cv=coefficient of variation
[Taken from Diederichsen, A. 2001. Comparison of genetic diversity of flax (*Linum usitatissimum L.*) between Canadian and a world collection. Plant Breeding 120:360-362.]

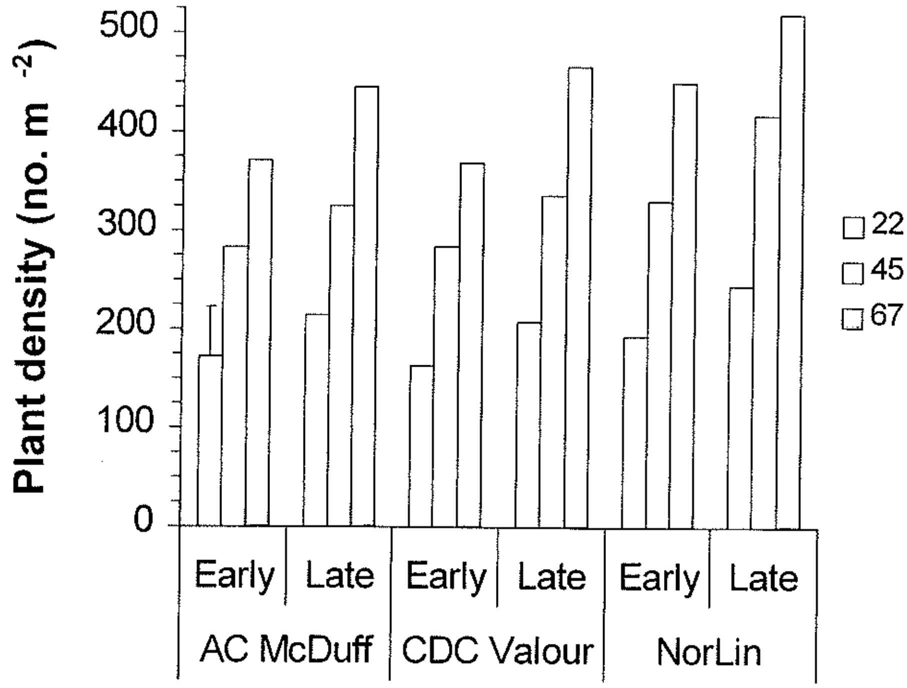

Figure 5.1. The effects of seeding date and cultivar on plant density (error bar LSD0.05).

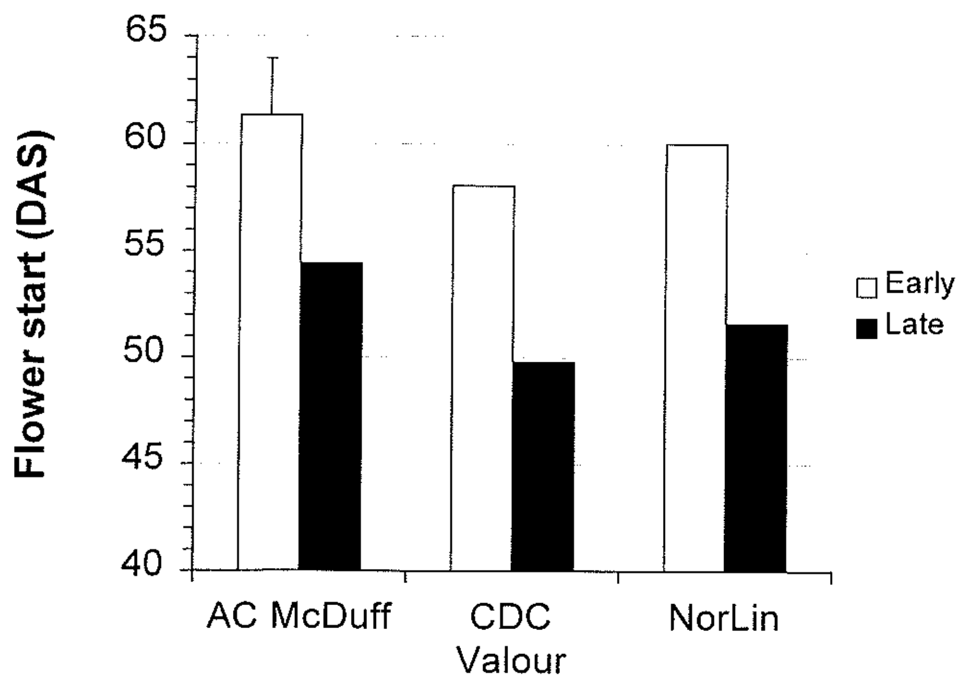

Figure 5.2. The effects of seeding date and cultivar on days to start of flowering (error bar LSD0.05).

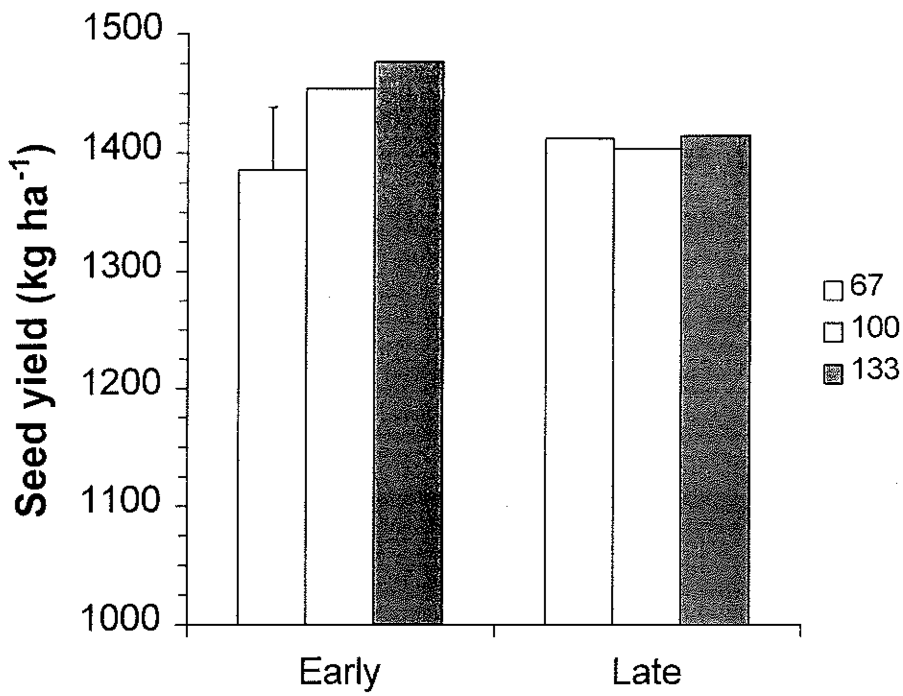

Figure 5.3. The effects of nitrogen rate and seeding date on seed yield (error bar LSD0.05).

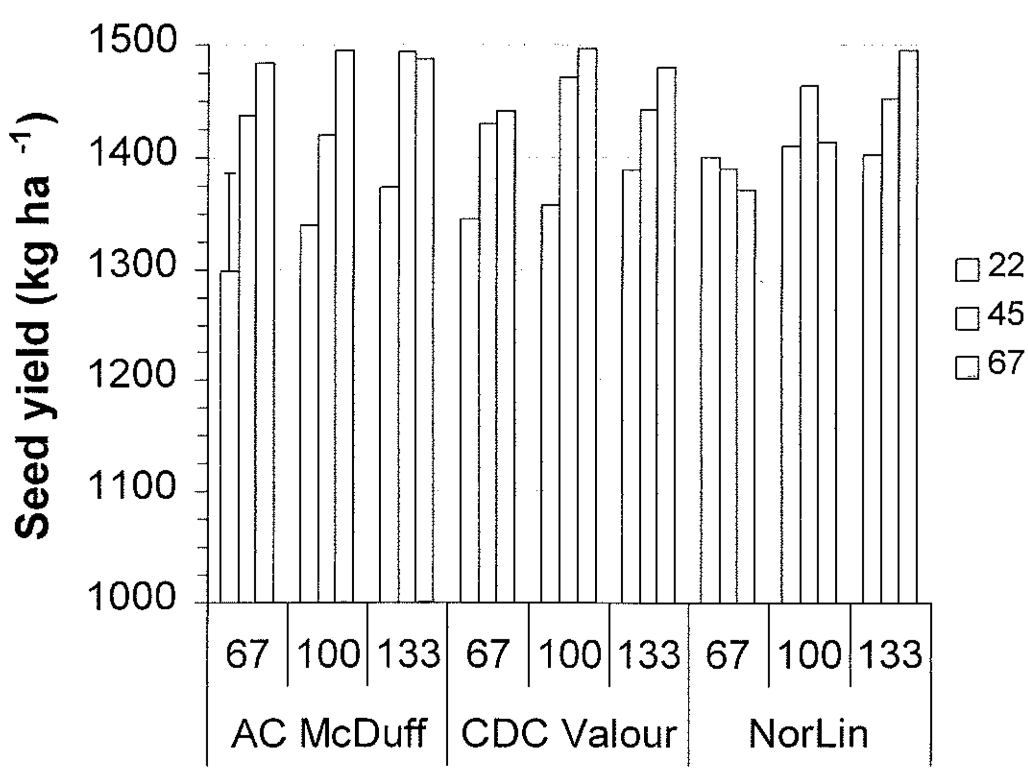

Figure 5.4. The effects of cultivar, nitrogen rate and seeding rate on seed yield (error bar LSD0.05).

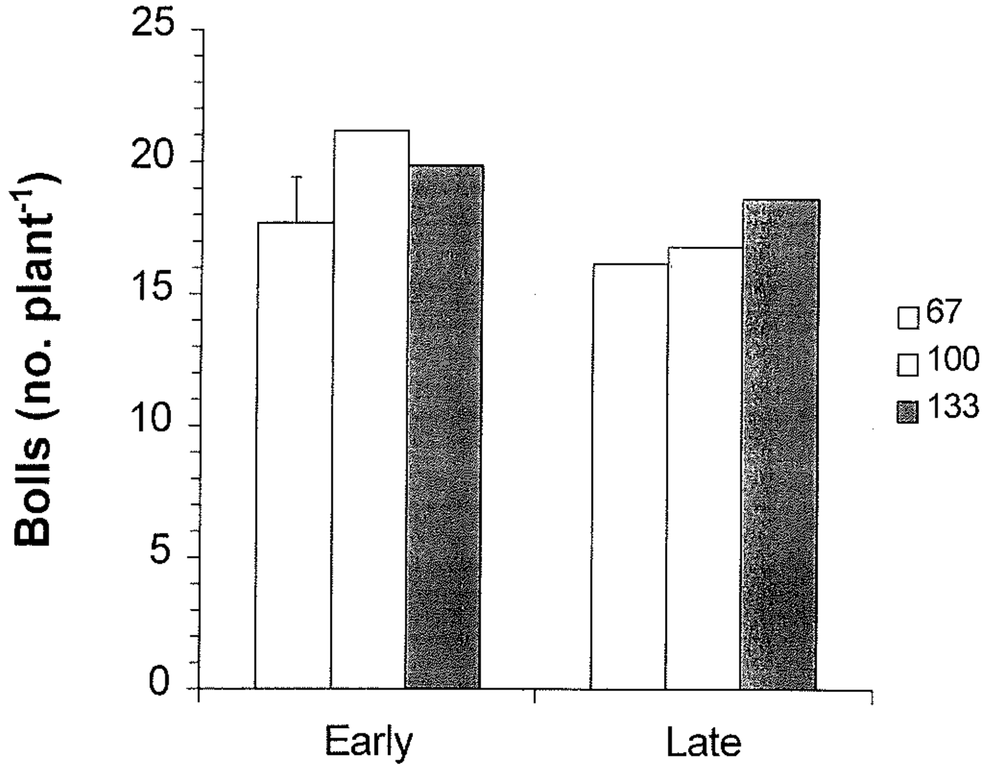

Figure 5.5. The effects of seeding date and nitrogen rate on bolls per plant (error bar LSD0.05).

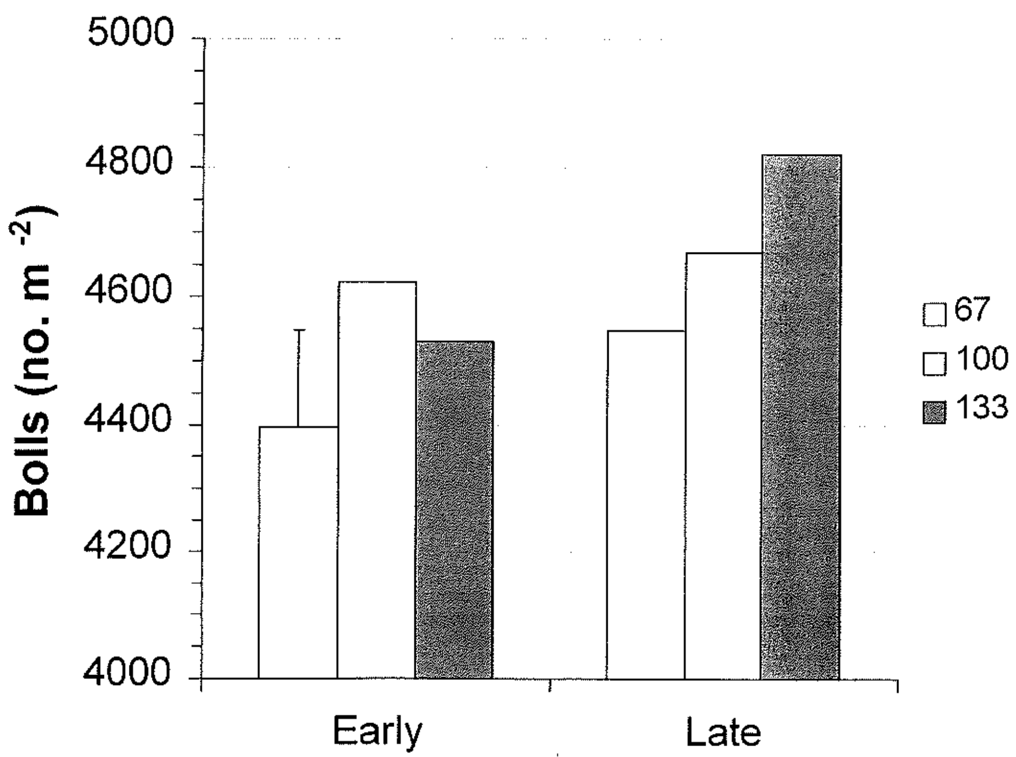

Figure 5.6. The effects of seeding date and nitrogen rate on bolls per unit area (error bar LSD0.05).

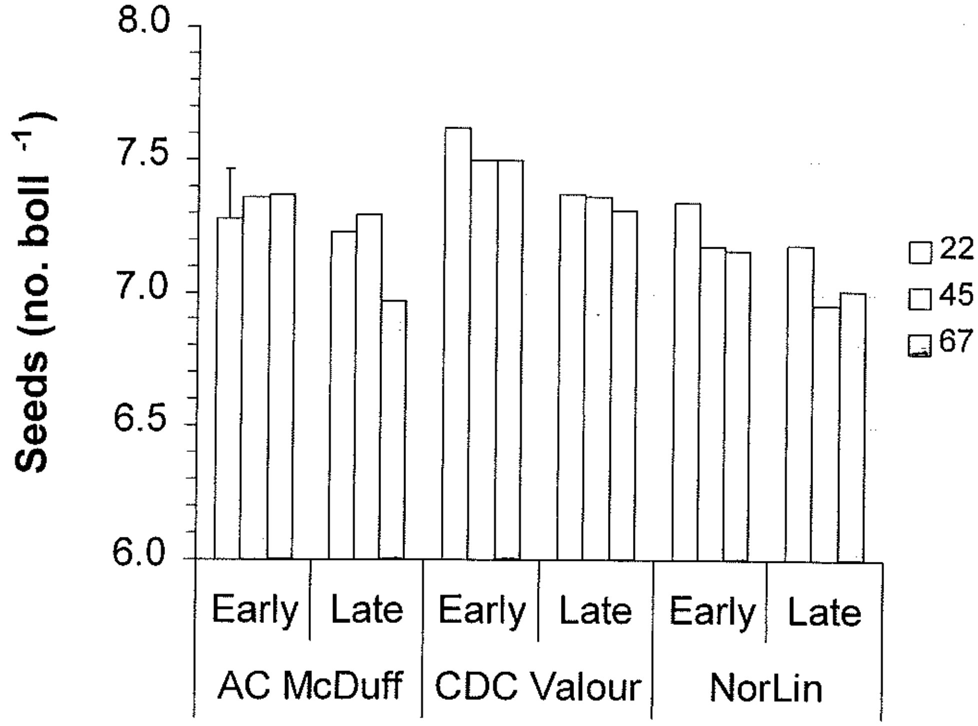

Figure 5.7. The effects of cultivar, seeding date and seeding rate on seeds per boll (error bar LSD0.05).

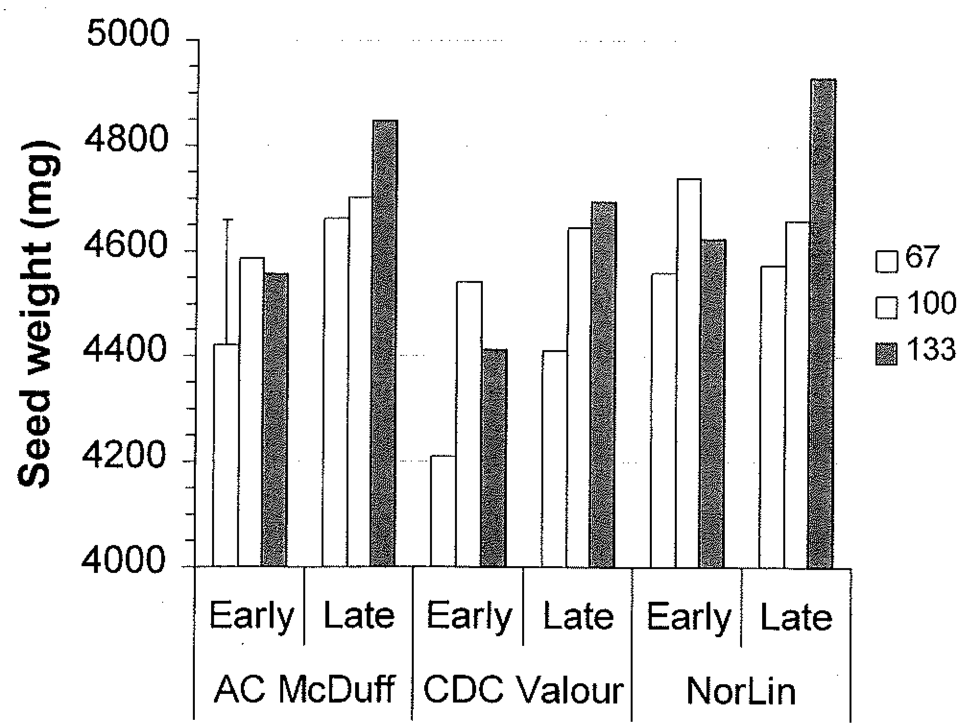

Figure 5.8. The effects of cultivar, seeding date and nitrogen rate on seed weight (error bar LSD0.005).

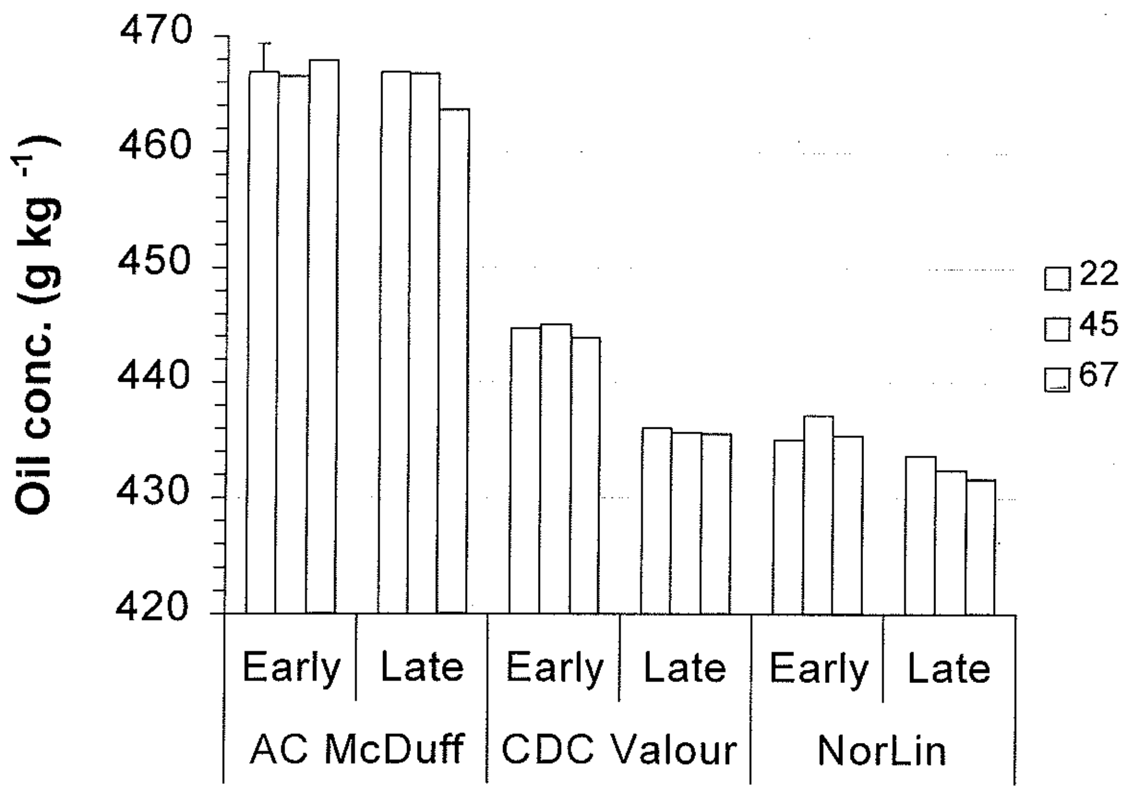

Figure 5.9. The effects of cultivar, seeding date and seeding rate on oil concentration (error bar LSD0.05).

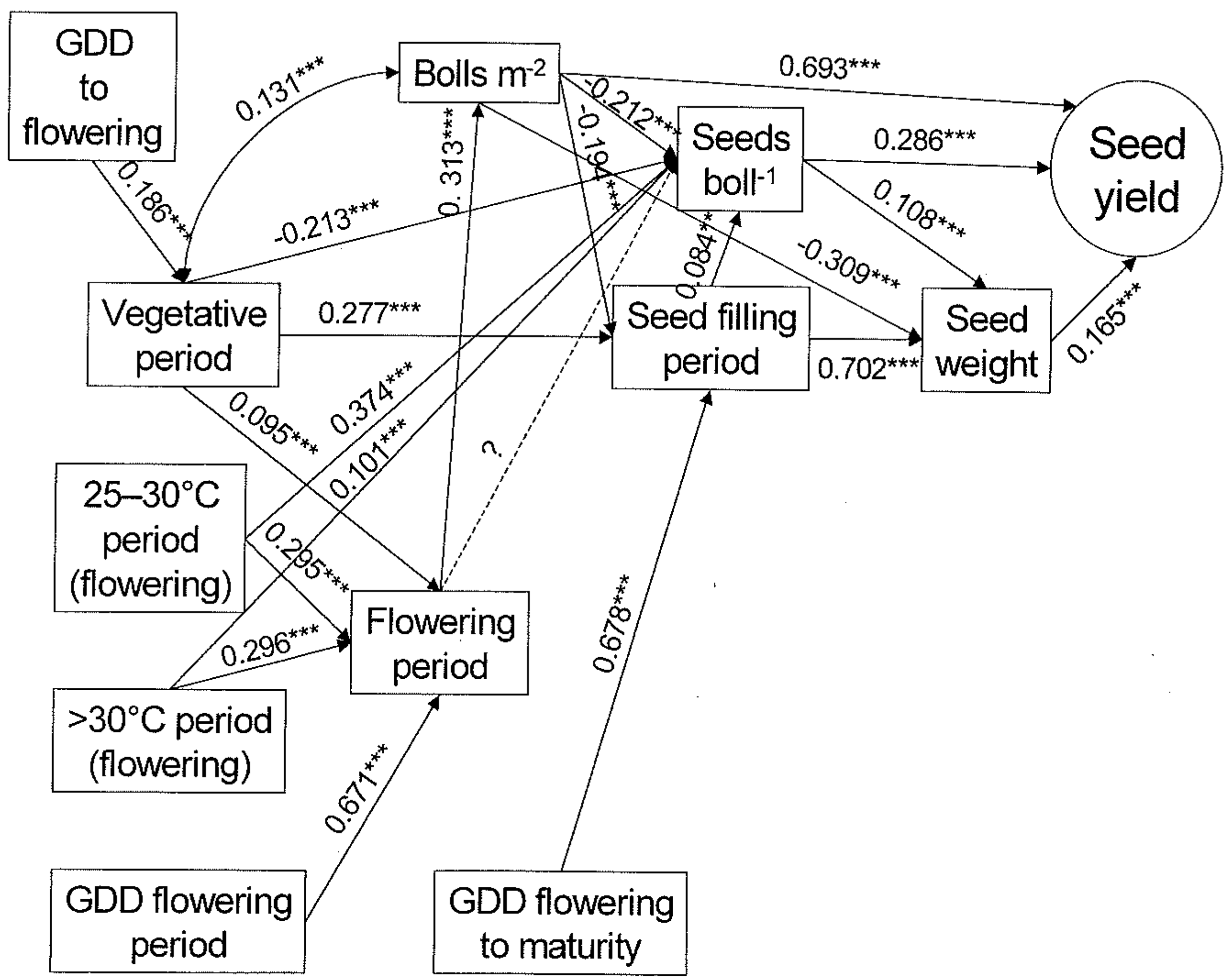

Figure 5.10. Path coefficient analysis.

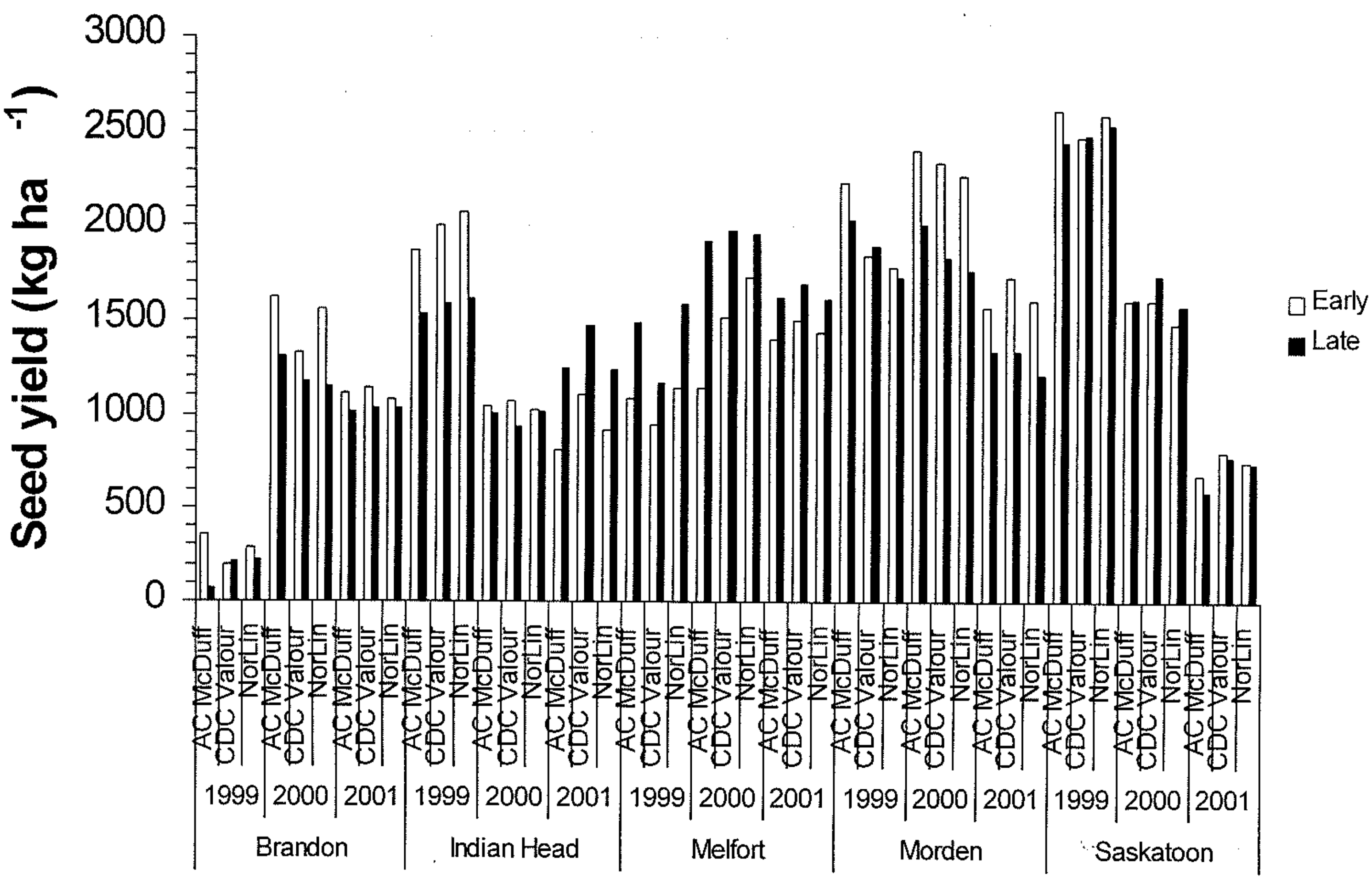

Figure 5.11. The effects of location cultivar and seeding date on seed yield.

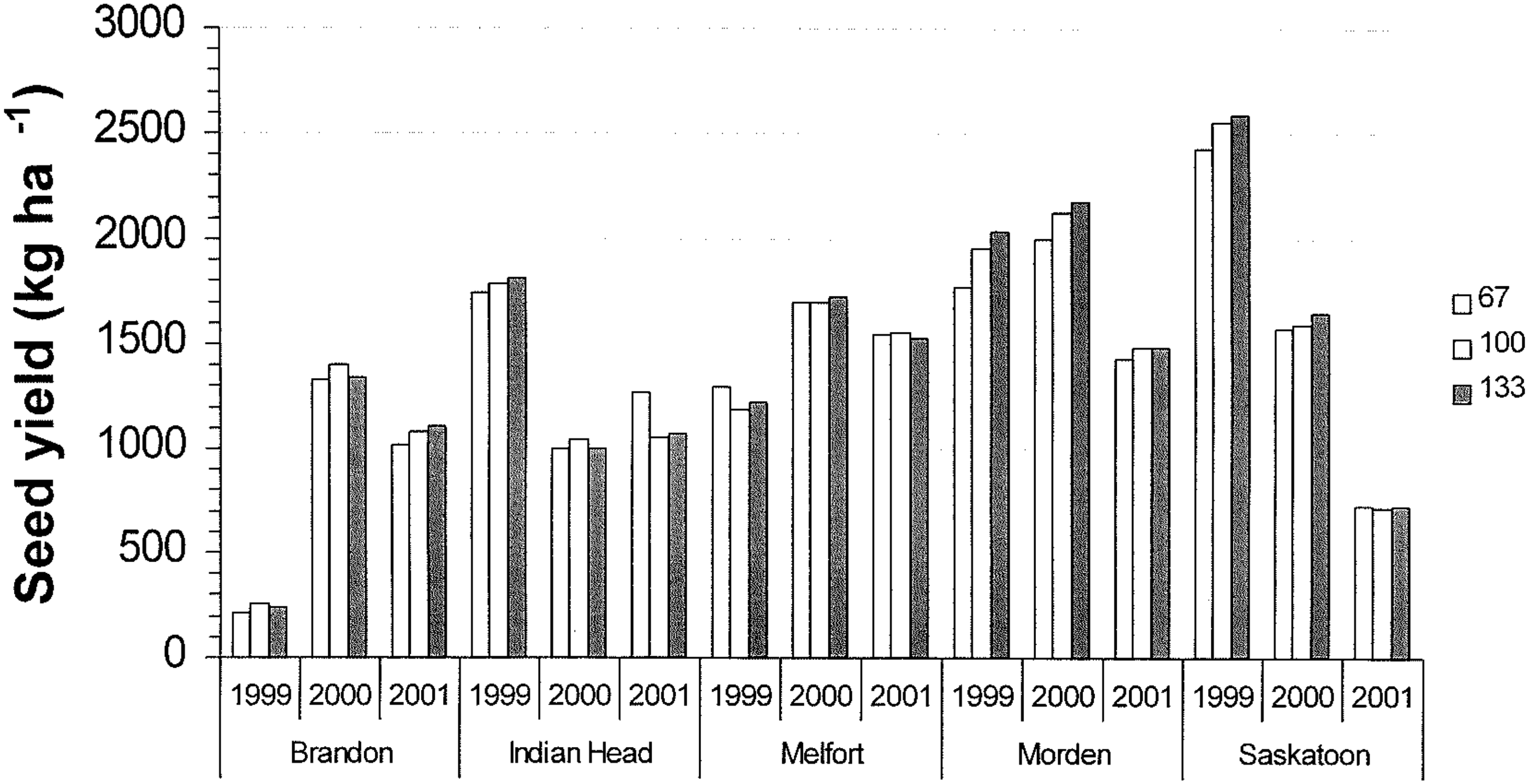

Figure 5.12. The effects of location, year and nitrogen on seed yield.

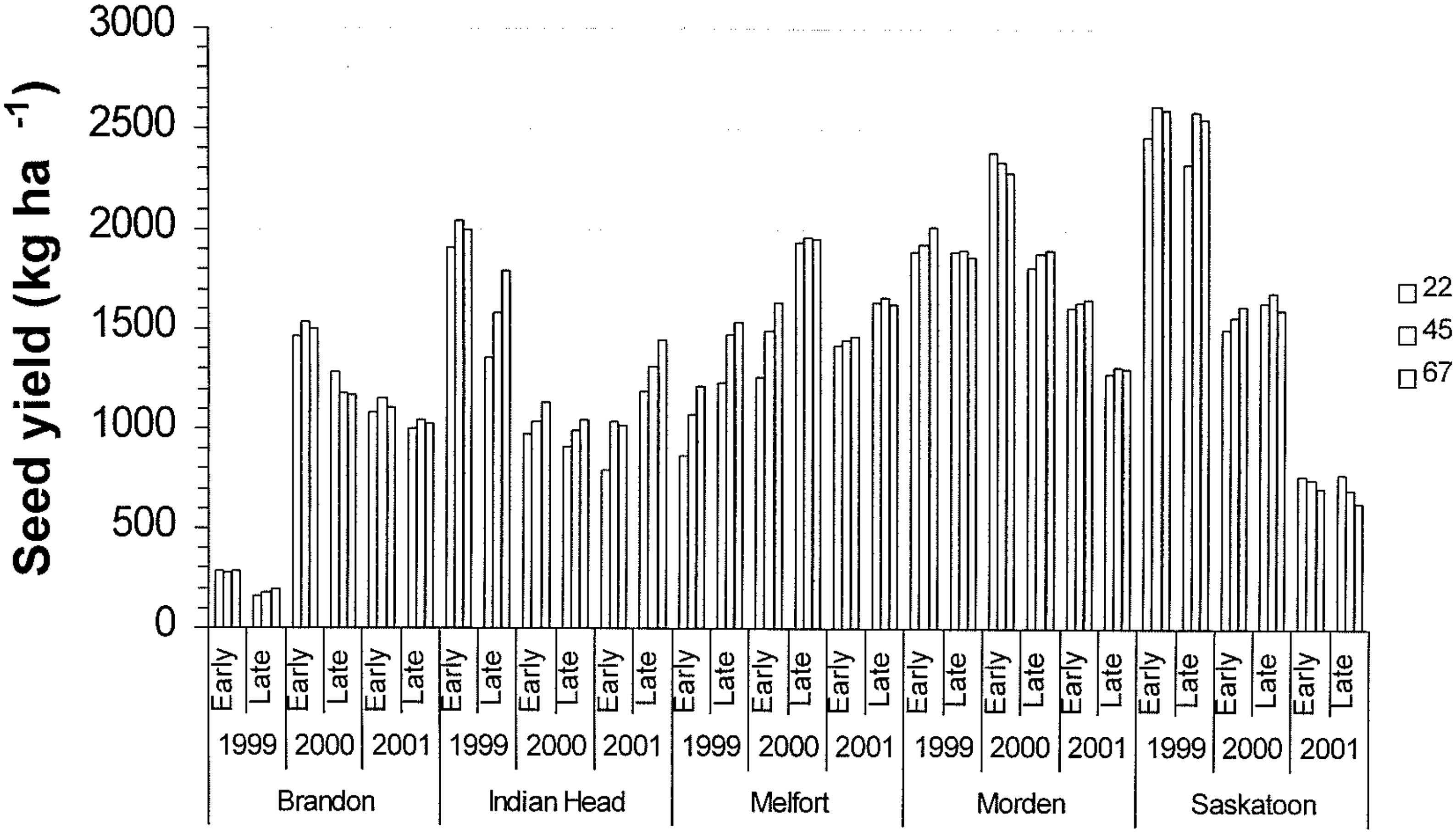

Figure 5.13. The effects of location, year, seeding date and seeding rate on seed yield.

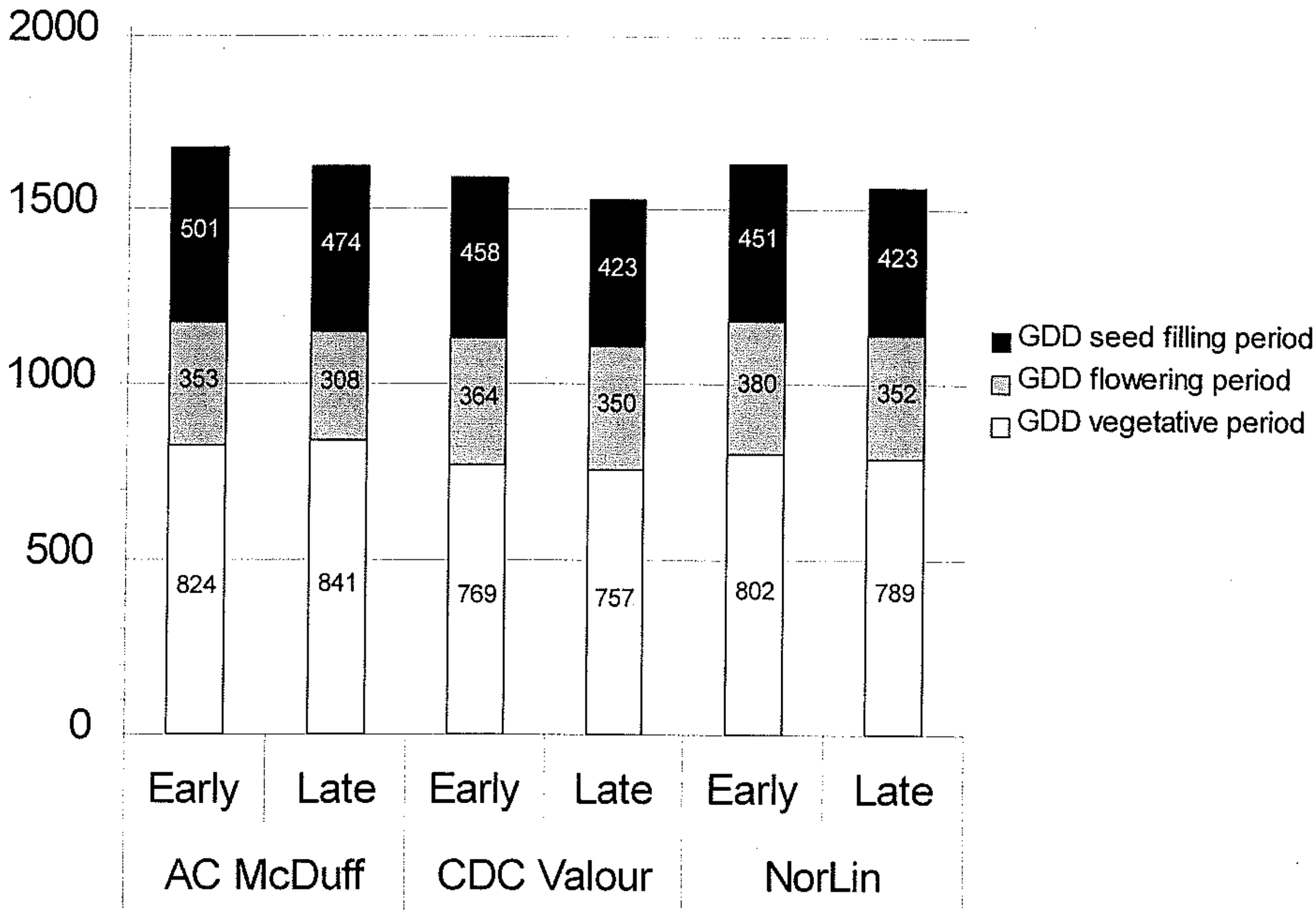

Figure 4. The effects of seeding date and cultivar on growing degree day accumulation for several periods.

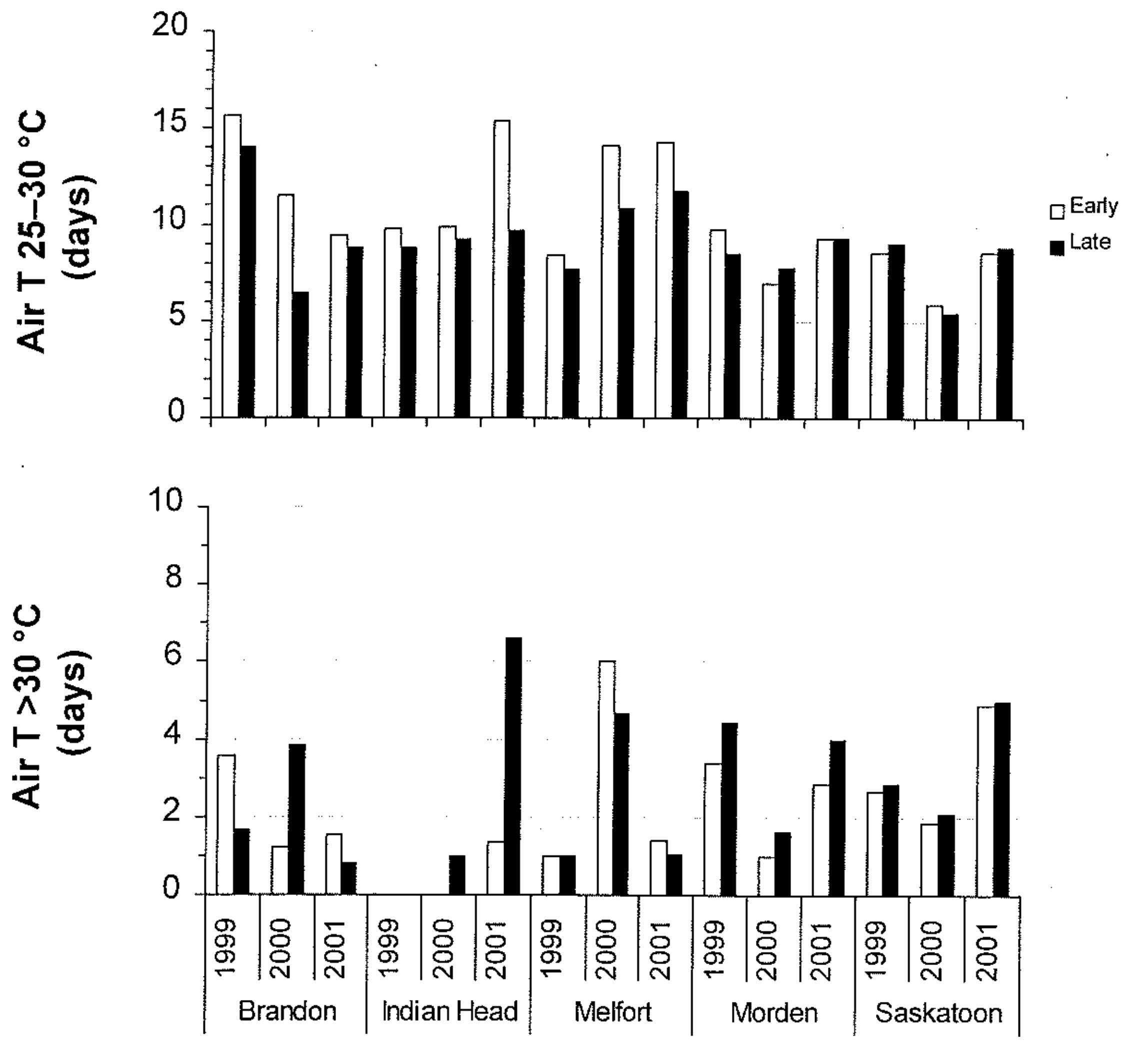

Figure 5.15. The number of days where maximum daily temperature were between 25 and 30C and greater than 30C during the start and end of flowering period.

6.0 Effects of Agronomic Factors on Flax Diseases

Flax (*Linum usitatissimum L.*) is a common oilseed crop with major productions areas in Manitoba and Saskatchewan in Canada, and in the Dakotas in USA. The crop is affected by several diseases which reduce the yield and quality of harvested seed. *Fusarium oxysporum* f.sp. *lini* (Bolley) Snyder & Hansen is a soil-borne fungus infects the flax plants at all growth stages and causes wilt and death of plants. *Melampsora lini* (Ehrenb.) Desmaz. is a stubble and air-borne fungus that causes flax rust and defoliates and kills the plants. *Septoria linicola* (Speg.) is a stubble-borne fungus that infects leaves and stems (pasmo) causing defoliation and lodging of weak stems. Powdery mildew is a recent disease affecting flax and is caused by the fungus *Oidium lini* Skoric. Other disease such as browning and stem break, seedling blights and damping-off, anthracnose, grey mold may be present and affect flax in different regions. Previous studies indicated that summer fallow and high fertility may increase crop vigor, produce dense canopy, cause lodging and result in higher incidence and severity of pasmo. The objectives of this study were to study the effects of different levels of nitrogen fertility, different cultivars, different seeding rates, and seeding dates on disease incidence and severity in flax.

6.1 Morden Trials 2000-2001:

The cultivars reacted differently with significant differences to the different diseases and to yellowing and lodging (Tables 6.1 to 6.2). McDuff was significantly more resistant to powdery mildew than NorLin and Valour. McDuff and NorLin were significantly more resistant to pasmo than Valour.

Nitrogen rates had no significant effects on diseases in Morden 2001 (Table 6.2) trials. In Morden 2000 (Table 1), Low and medium nitrogen rates had significantly reduced pasmo and lodging but no significant effects on powdery mildew.

Seeding rates in general had little effect on diseases. However, in Morden 2000, the low seeding rate significantly reduced the early pasmo leaf spots, yellowing, final pasmo and AUDPC, and lodging, while the high rate of seeding significantly reduced powdery mildew (Table 6.1).

Late seeding significantly reduced leaf spots by pasmo, yellowing, pasmo and lodging (Tables 6.1-6.2), and powdery mildew in Morden 2001 trial (Table 6.22). Early seeding date had significantly less powdery mildew only in the Morden 2000 trial (Table 6.1).

Some significant interactions between cultivar/seeding dates, cultivar nitrogen rates, and seeding dates and nitrogen rates for pasmo and lodging at Morden (Table 6.1-6.2).

6.2 Brandon Trials 2000-2001:

The cultivars reacted differently to the different diseases and to yellowing and lodging (Tables 6.3-6.4). McDuff was significantly more resistant to powdery mildew than NorLin and Valour, and McDuff and Valour were had significantly less yellowing NorLin. McDuff and NorLin were significantly more resistant to pasmo than Valour.

Nitrogen rates had no significant effects on diseases in Brandon 2000 (Table 6.3). In Brandon 2001 trials, Low and medium nitrogen rates had significantly reduced pasmo and lodging (Table 6.4). Medium and high nitrogen rates resulted in significantly less yellowing in Brandon in 2001.

Seeding rates had no significant effects on powdery mildew in Brandon 2000 trial, but the low seeding rate resulted in significantly lower leaf infections, lower yellowing, lower pasmo and less lodging (Table 6.3).

Late seeding date significantly reduced leaf spots by pasmo, yellowing, pasmo and lodging (Tables 6.3-6.4), but had significantly more powdery mildew in Brandon 2000 trial (Table 6.3).

The only significant interaction was between cultivar and seeding dates for leaf and stem infections by pasmo in 2000 (Table 3), and pasmo and powdery mildew in 2001 (Table 6.4).

6.3 Indian Head Trials 2000-2001:

The cultivars reacted differently with significant differences to the different diseases and to yellowing and lodging (Tables 6.5-6.6). McDuff and NorLin were significantly more resistant to pasmo and lodging than Valour, while Valour had less early leaf infections than McDuff and NorLin in 2000 (Tables 6.5-6.6). There were no significant powdery mildew infections at Indian Head in both years.

Nitrogen rates had no significant effects on diseases in Indian Head in 2001 trial (Table 6.6), while medium and low rates reduced early yellowing in 2000 (Table 6.5). High nitrogen rate resulted in significantly lower pasmo and less lodging in 2000 (Table 6.5).

Low seeding rate resulted in significantly lower leaf infections in 2000, and lower pasmo in both years (Tables 6.5-6.6).

Late seeding date significantly reduced yellowing and pasmo, but resulted in significantly higher early leaf infections by pasmo (Tables 6.5-6.6).

There were significant interactions between cultivar/seeding dates, seeding rates and dates, cultivar/seeding rates and dates for pasmo in 2001 (Table 6.6)

6.4 Melfort Trials 2000-2001:

The cultivars reacted differently with significant differences to the different diseases and to yellowing and lodging (Tables 6.7-6.8). McDuff was significantly more resistant to early leaf infections by pasmo, and to powdery mildew than NorLin and Valour in 2000 (Table 6.7). McDuff and NorLin were significantly more resistant to pasmo and lodging than Valour (Table 6.7)

Nitrogen rates had no effects on powdery mildew and early or late leaf infections, but the high rate significantly reduced pasmo in 2000 (Table 6.7).

Seeding rates had no effects on early or late leaf infections, but the low and medium seeding rates had significantly reduced pasmo and lodging (Table 6.7)

Seeding dates had no effects on powdery mildew, pasmo and late leaf infections, but the early seeding date significantly reduced early leaf infections, yellowing and lodging in 2000 (Table 6.7).

No significant diseases were observed in 2001 in Melfort because of the dry weather prevailing throughout the growing season (Table 6.8).

There were significant interactions between cultivars and seeding dates for leaf and stem pasmo infections, and for lodging in 2000 (Table 6.7).

6.5 Saskatoon Trials 2000-2001:

In the Saskatoon trial in 2000, there was unique symptoms of mottling on the lower leaves at the early assessment date, and reddish discoloration on the stems at the late assessment date. These symptom were not associated with any pathogenic causal agent, and were perhaps related to physiological expressions of some deficiencies or toxicity of micronutrients or herbicides in the soil.

The cultivars reacted differently with significant differences to the different diseases and to yellowing and mottling on the leaves and reddish discoloration of the stems in Saskatoon 2000 trial (Table 6.9). McDuff and NorLin were significantly more resistant to pasmo than Valour. McDuff and Valour were less affected by reddish stem discoloration than NorLin, while they have significantly more leaf mottling than NorLin. NorLin and Valour had significantly less early leaf infections by pasmo.

Nitrogen rates had no significant effects on diseases in Saskatoon, except for the significantly low mottling at the high nitrogen rate in 2000 (Table 6.9).

Seeding rates had no effects on mottling or yellowing in 2000. The low seeding rate had significantly reduced early leaf infection and pasmo, while the medium and high seeding rated had significantly reduced reddish stem discoloration (Table 6.9).

Late seeding date significantly reduced pasmo, while early seeding date significantly reduced the reddish stem discoloration in 2000 (Table 6.9).

There were no significant diseases observed in Saskatoon 2001 because of the dry weather prevailing throughout the growing season (Table 6.10).

There were significant interactions between cultivar/nitrogen rates /seeding dates for mottling, and between nitrogen and seeding rates/seeding dates for reddish stem discoloration in Saskatoon 2000 (Table 6.9)

Conclusions:

Pasmo and powdery mildew were the most common and severe diseases observed in a descending order of severity, respectively, at Morden, Brandon, Melfort, Indian Head and Saskatoon. Lodging, heavy stand and seeding rates, high nitrogen and vigour, were always associated with significantly high pasmo. Pasmo was more severe at the early seeding dates in all locations. Powdery mildew was sometimes more severe in late seeding dates but this was not always consistent. Powdery mildew was not generally affected by seeding rates or nitrogen levels but most likely by the humidity and temperature prevailing from mid-season onward to the end of the season. Resistant cultivars exist for powdery mildew and it was apparent in this study that AC McDuff was much more resistant than Norlin or CDC Valour. Other cultivars such as AC Watson, AC Emerson, AC Hanley, AC Lightning, CDC Bethune and Flanders are more resistant than cultivars such as Norman, NorLin, Somme, Vimy, CDC Arras and CDC Normandy. As for pasmo, the differences between cultivars were not dramatic, however, we did observe in these trials that AC McDuff and sometimes Norlin were less susceptible than CDC Valour.

Therefore the recommendation of seeding recommended rates of resistant cultivars(in this case to powdery mildew and pasmo), and avoiding very early seeding and high nitrogen rates will result in a less dense canopy which is less favorable for pasmo and perhaps avoid high powdery mildew severity. The reduction in disease levels with the later seeding dates is not always consistent with the observations for yield.

Table 6.1. Disease evaluation - Morden 2000.

	Early Leaf Lesions	Early Yellowing	Late Leaf Lesions	Early Powdery Mildew	Late Yellowing	Defoliation	Lodging	Late Powdery Mildew	Mean Pasmo	Pasmo (Area Under Disease Curve)
Cultivar	NS		NS							
1 (McDuff)	1.61	1.78 *	2.91	0.04 *	2.96 *	1.11 *	0.00 *	0.06 *	2.81 *	7.20 *
2 (NorLin)	1.61	3.00	2.94	0.26 *	3.56	1.57	0.00 *	2.61	3.07 *	7.86 *
3 (Valour)	1.54	1.98 *	2.94	0.74	3.00 *	1.69	0.54	2.85	4.14	10.56
LSD (0.05)	0.29	0.39	0.28	0.36	0.26	0.27	0.24	0.62	0.28	0.71
Nitrogen Rate	NS		NS	NS				NS		
N1 (66%)	1.52	2.59	2.91	0.19	3.52	1.63	0.00 *	1.69	2.97 *	7.56 *
N2 (100%)	1.65	2.02 *	2.87	0.54	3.11 *	1.33 *	0.13 *	2.09	3.39	8.69
N3 (133%)	1.59	2.15 *	3.02	0.31	2.89 *	1.41	0.41	1.74	3.66	9.39
LSD (0.05)	0.29	0.39	0.28	0.36	0.26	0.27	0.24	0.62	0.28	0.71
Seed Rate				NS						
1 (22)	1.37 *	1.46 *	2.67 *	0.35	2.91 *	1.30 *	0.07 *	2.22	2.92 *	7.43 *
2 (47)	1.59 *	2.19 *	3.00	0.35	3.22	1.50	0.11 *	2.06	3.50	8.96
3 (67)	1.80	3.11	3.13	0.33	3.40	1.57	0.35	1.24 *	3.60	9.24
LSD (0.05)	0.29	0.39	0.28	0.36	0.26	0.27	0.24	0.62	0.28	0.71
Seed Date				NS						
1 (Early)	1.75	2.46	3.73	0.49	3.80	2.30	0.33	1.56 *	4.08	11.91
2 (Late)	1.42 *	2.05 *	2.14 *	0.20	2.54 *	0.62 *	0.02 *	2.12	2.60 *	5.18 *
LSD (0.05)	0.24	0.32	0.23	0.39	0.21	0.21	0.20	0.51	0.23	0.58
RP	**	-	-	-	*	-	-	**	*	*
CL	-	**	-	**	**	**	**	**	**	**
NR	-	*	-	-	**	*	*	-	**	**
CLxNR	-	-	-	-	-	-	**	-	*	*
SR	*	**	*	-	*	-	*	*	**	**
CLxSR	-	*	-	-	*	-	*	-	-	-
NRxSR	-	*	-	-	-	-	*	-	-	-
CLxNRxSR	-	-	-	-	-	-	*	-	-	-
SD	*	*	**	*	**	**	*	*	**	**
CLxSD	-	*	-	*	-	-	**	-	**	**
NRxSD	-	*	-	-	-	-	*	-	*	*
CLxNRxSD	-	-	-	-	-	-	*	-	-	-
SRxSD	*	-	-	-	*	*	-	-	-	-
CLxSRxSD	-	-	-	-	-	-	-	-	-	-
NRxSRxSD	*	-	*	-	-	*	-	-	-	-
CLxNRxSRxSD	-	-	-	-	-	-	-	-	-	-

Table 6.2. Disease Evaluation - Morden 2001.

	Mottling	Leaf Lesions	Yellowing	Early Powdery Mildew	Late Powdery Mildew	Mean Pasmo	Pasmo (Area Under Disease Curve)	Lodging
Cultivar		NS						
1 (McDuff)	3.3 *	0.13	0.20 *	1.1 **	1.1 **	3.9 *	8.9	0.03 **
2 (NorLin)	5.8	0.19	0.33	4.3	5.0 *	3.0 *	7.1 *	0.2 *
3 (Valour)	4.8 *	0.22	0.24	4.4	5.2	3.7	9.5	0.7
LSD (0.05)	0.6	0.15	0.11	0.3	0.2	0.3	0.7	0.2
Nitrogen Rate	NS	NS	NS	NS	NS	NS	NS	NS
Seed Rate		NS		NS	NS	NS	NS	NS
1 (22)	4.2 *	0.19	0.07 **	3.2	3.7	3.5	8.1	0.4
2 (47)	4.8	0.19	0.28 *	3.4	3.9	3.7	8.7	0.3
3 (67)	4.9	0.17	0.43	3.2	3.8	3.5	8.7	0.2
LSD (0.05)	0.6	0.15	0.11	0.3	0.2	0.3	0.7	0.2
Seed Date								
1 (Early)	5.5	0.28	0.52	3.8	4.5	3.8	12.4	0.16 *
2 (Late)	3.8 *	0.07 *	0.00 **	2.7 *	3.0 *	3.3 *	4.6 **	0.42
LSD (0.05)	0.5	0.13	0.09	0.2	0.2	0.2	0.6	0.17
RP	**	-	-	-	*	*	**	*
CL	**	-	*	**	**	**	**	**
NR	-	-	-	-	-	-	-	-
CLxNR	-	-	-	-	-	-	-	-
SR	*	-	**	-	-	-	-	-
CLxSR	-	-	-	-	-	*	-	-
NRxSR	-	-	-	-	-	-	-	-
CLxNRxSR	-	-	-	-	-	-	-	-
SD	**	*	**	**	**	**	**	*
CLxSD	-	-	*	**	**	**	**	*
NRxSD	-	-	-	-	-	-	-	*
CLxNRxSD	-	-	-	-	-	-	-	-
SRxSD	*	-	**	-	*	-	-	-
CLxSRxSD	-	-	-	-	-	-	-	-
NRxSRxSD	-	-	-	-	-	-	-	-
CLxNRxSRxSD	-	-	-	-	-	-	-	-

Table 6.3. Disease Evaluation - Brandon 2000.

	Early Lodging		Early Leaf Lesions		Early Yellowing		Defoliation		Late Leaf Lesions		Pasmo		Powdery Mildew		Late Lodging	
Cultivar									NS							
1 (McDuff)	0.06	*	1.76		0.31	*	0.15	*	7.15		2.61	*	0.07	*	0.74	*
2 (NorLin)	0.15	*	1.61		0.61		0.09	*	6.90		2.96	*	1.69		2.74	*
3 (Norlin_60)	0.00	*	1.50	*	0.92		0.00	*	7.33		3.58		1.67		2.58	*
4 (Valour)	1.39		1.96		0.59		0.54		6.97		4.15		1.43		4.89	
LSD (0.05)	0.65		0.38		0.33		0.27		0.67		0.73		0.83		1.10	
Nitrogen Rate	NS						NS		NS		NS		NS			
N1 (50%)	0.00		1.33	*	1.00		0.00		7.60		2.67		1.17		1.33	*
N2 (66%)	0.43		1.85		0.59		0.30		7.16		3.17		1.02		2.78	
N3 (100%)	0.42		1.70		0.48	*	0.22		7.02		3.53		1.08		2.78	
N4 (133%)	0.70		1.78		0.48	*	0.24		6.87		3.13		1.20		2.93	
LSD (0.05)	0.82		0.48		0.42		0.34		0.79		0.92		1.10		1.35	
Seed Rate									NS				NS			
1 (22)	0.26	*	1.61	*	0.31	*	0.13	*	6.95		2.78	*	0.98		2.41	*
2 (47)	0.36	*	1.64	*	0.58		0.20	*	6.98		3.23	*	1.30		2.61	
3 (67)	0.89		2.06		0.70		0.41		7.23		3.80		0.98		3.35	
LSD (0.05)	0.46		0.27		0.24		0.19		0.47		0.52		0.59		0.76	
Seed Date	NS		NS		NS		NS									
1 (Early)	0.48		1.69		0.62		0.28		7.71		5.40		0.30	*	2.15	*
2 (Late)	0.51		1.83		0.45		0.21		6.71	*	1.13	*	1.91		3.40	
LSD (0.05)	0.37		0.22		0.19		0.16		0.40		0.42		0.48		0.62	
RP	*		-		**		*		-		**		*		**	
CL	**		*		*		**		-		**		**		**	
NR	-		-		-		-		-		-		-		-	
CLxNR	-		-		-		-		-		-		-		-	
SR	*		*		*		*		-		-		-		*	
CLxSR	-		-		-		*		-		-		-		-	
NRxSR	*		-		-		-		-		-		-		-	
CLxNRxSR	*		-		-		-		-		-		-		*	
SD	-		-		*		-		**		**		**		**	
CLxSD	-		-		*		*		*		*		**		-	
NRxSD	-		-		-		-		-		-		-		-	
CLxNRxSD	-		-		-		-		-		-		-		-	
SRxSD	-		-		-		-		-		-		-		-	
CLxSRxSD	-		-		-		-		-		-		-		-	
NRxSRxSD	-		-		-		-		-		-		-		-	
CLxNRxSRxSD	-		-		-		-		-		-		-		-	

Table 6.4. Disease Evaluation - Brandon 2001.

	Yellowing		Pasmo		Lodging		Weeds	
Cultivar							NS	
1 (McDuff)	0.65	*	3.5	*	0.15	*	0.61	
2 (NorLin)	0.98		3.9		0.24	*	0.70	
3 (Valour)	0.57	*	5.5	*	1.07		0.59	
LSD (0.05)	0.12		0.3		0.28		0.21	
Nitrogen Rate								
N1 (66%)	0.89		4.0	*	0.35	*	0.52	*
N2 (100%)	0.74	*	4.3	*	0.39	*	0.61	
N3 (133%)	0.57	*	4.6		0.72		0.78	
LSD (0.05)	0.12		0.3		0.28		0.21	
Seed Rate	NS		NS		NS			
1 (22)	0.72		4.2		0.56		0.74	
2 (47)	0.72		4.3		0.33		0.67	
3 (67)	0.76		4.4		0.57		0.50	*
LSD (0.05)	0.12		0.3		0.28		0.21	
Seed Date							NS	
1 (Early)	1.4		6.1		0.74		0.67	
2 (Late)	0.1	**	2.5	**	0.24	*	0.61	
LSD (0.05)	0.1		0.2		0.23		0.17	
RP	**		-		**		**	
CL	**		**		**		-	
NR	**		**		*		*	
CLxNR	-		-		-		-	
SR	-		-		-		*	
CLxSR	-		-		-		*	
NRxSR	-		-		-		-	
CLxNRxSR	-		-		-		-	
SD	**		**		**		-	
CLxSD	**		**		**		-	
NRxSD	**		-		-		-	
CLxNRxSD	**		-		-		-	
SRxSD	-		*		-		-	
CLxSRxSD	-		-		-		-	
NRxSRxSD	*		-		-		*	
CLxNRxSRxSD	*		-		-		-	

Table 6.5. Disease Evaluation - Indian Head 2000.

	Stand		Vigor		Early Leaf lesions		Early Yellowing		Pasmo		Lodging	
Cultivar												
1 (McDuff)	1.63	*	1.44		0.80		0.11	*	5.70	*	0.48	*
2 (NorLin)	1.85		1.24	*	0.85		0.26		5.63	*	0.41	*
3 (Valour)	1.72		1.37		0.65	*	0.17		6.39		1.37	
LSD (0.05)	0.19		0.15		0.16		0.14		0.33		0.47	
Nitrogen Rate			NS		NS							
N1 (66%)	1.63	*	1.33		0.76		0.07	*	6.09		0.85	
N2 (100%)	1.93		1.37		0.70		0.02	*	6.04		1.19	
N3 (133%)	1.65	*	1.35		0.83		0.44		5.59	*	0.22	*
LSD (0.05)	0.19		0.15		0.16		0.14		0.33		0.47	
Seed Rate							NS				NS	
1 (22)	2.39		1.67		0.61	*	0.11		5.46	*	0.70	
2 (47)	1.63	*	1.30	*	0.81		0.20		6.15		0.78	
3 (67)	1.19	*	1.09	*	0.87		0.22		6.11		0.78	
LSD (0.05)	0.19		0.15		0.16		0.14		0.33		0.47	
Seed Date	NS										NS	
1 (Early)	1.73		1.27	*	0.69	*	0.32		6.94		0.90	
2 (Late)	1.74		1.43		0.84		0.04	*	4.88	*	0.60	
LSD (0.05)	0.15		0.12		0.13		0.11		0.27		0.38	
RP	-		*		**		*		-		-	
CL	*		*		*		*		**		**	
NR	*		-		-		**		*		*	
CLxNR	*		-		-		-		*		-	
SR	**		**		*		-		**		-	
CLxSR	-		-		-		-		*		*	
NRxSR	*		-		-		-		-		-	
CLxNRxSR	*		-		-		-		-		-	
SD	-		*		*		**		**		-	
CLxSD	-		-		-		*		-		-	
NRxSD	-		-		-		**		-		*	
CLxNRxSD	*		-		-		-		-		-	
SRxSD	-		-		-		-		-		-	
CLxSRxSD	-		-		-		-		-		-	
NRxSRxSD	-		-		-		-		-		-	
CLxNRxSRxSD	-		-		-		-		-		*	

Table 6.6. Disease Evaluation - Indian Head 2001.

	Pasmo		Stand	
Cultivar				
1 (McDuff)	0.53	*	2.2	
2 (NorLin)	0.26	**	2.1	
3 (Valour)	1.08		1.8	*
LSD (0.05)	0.28		0.1	
Nitrogen Rate	NS			
N1 (66%)	0.67		1.7	*
N2 (100%)	0.65		2.1	*
N3 (133%)	0.56		2.2	
LSD (0.05)	0.28		0.1	
Seed Rate				
1 (22)	0.37	*	2.4	
2 (47)	0.67		1.9	*
3 (67)	0.83		1.7	*
LSD (0.05)	0.28		0.12	
Seed Date				
1 (Early)	1.1		2.3	
2 (Late)	0.1	*	1.7	*
LSD (0.05)	0.2		0.1	
RP	-		-	
CL	**		**	
NR	-		**	
CLxNR	-		-	
SR	**		**	
CLxSR	-		*	
NRxSR	-		*	
CLxNRxSR	-		-	
SD	**		**	
CLxSD	**		**	
NRxSD	-		-	
CLxNRxSD	-		*	
SRxSD	*		**	
CLxSRxSD	*		**	
NRxSRxSD	-		-	
CLxNRxSRxSD	-		-	

Table 6.7. Disease Evaluation - Melfort 2000.

	Stand	Early Leaf Lesions	Early Yellowing	Powdery Mildew	Pasmo	Late Leaf Lesions	Lodging	Weeds
Cultivar						NS		
1 (McDuff)	2.61	0.70 *	0.04 *	0.06 *	2.69 *	7.39	0.04 *	1.46
2 (NorLin)	1.70 *	0.85	0.24	0.80	4.20 *	7.55	0.20 *	0.48 *
3 (Valour)	2.07 *	0.80	0.07 *	0.56	5.17	7.57	1.54	0.98 *
LSD (0.05)	0.21	0.15	0.11	0.39	0.36	0.55	0.35	0.33
Nitrogen Rate	NS	NS		NS		NS		NS
N1 (66%)	2.15	0.83	0.11 *	0.35	4.04	7.52	0.35 *	1.07
N2 (100%)	2.07	0.78	0.02 *	0.65	4.22	7.41	0.91	0.98
N3 (133%)	2.17	0.74	0.22	0.41	3.80 *	7.50	0.52 *	0.87
LSD (0.05)	0.21	0.15	0.11	0.39	0.36	0.51	0.35	0.33
Seed Rate		NS	NS			NS		
1 (22)	2.59	0.69	0.07	0.67	3.33 *	7.50	0.22 *	1.30
2 (47)	2.09 *	0.83	0.13	0.50	4.04 *	7.27	0.67	0.96 *
3 (67)	1.70 *	0.83	0.15	0.24 *	4.69	7.75	0.89	0.67 *
LSD (0.05)	0.21	0.15	0.11	0.39	0.36	0.53	0.35	0.33
Seed Date				NS	NS	NS		
1 (Early)	2.73	0.64 *	0.06 *	0.47	4.16	7.61	0.35 *	1.81
2 (Late)	1.53 *	0.93	0.17	0.47	3.88	7.37	0.84	0.14 *
LSD (0.05)	0.17	0.12	0.09	0.32	0.30	0.42	0.29	0.27
RP	**	*	-	*	*	*	**	**
CL	**	-	*	**	**	-	**	**
NR	-	-	*	-	*	-	*	-
CLxNR	-	*	-	-	-	-	-	-
SR	**	*	-	*	**	-	*	*
CLxSR	-	-	-	-	-	-	*	-
NRxSR	-	*	*	-	-	-	-	-
CLxNRxSR	-	-	-	-	-	-	-	-
SD	**	**	*	-	*	-	**	**
CLxSD	-	*	-	-	**	*	**	**
NRxSD	-	-	-	-	-	-	-	-
CLxNRxSD	-	-	-	*	-	-	-	-
SRxSD	-	-	-	-	*	-	*	*
CLxSRxSD	-	-	-	-	-	-	*	-
NRxSRxSD	-	-	*	-	-	*	-	-
CLxNRxSRxSD	-	-	-	-	-	-	-	-

Table 6.8. Disease Evaluation - Melfort 2001.

	Stand		Vigor		WEEDS	
Cultivar					NS	
1 (McDuff)	1.5	*	2.0		0.22	
2 (NorLin)	1.7	*	1.8	*	0.32	
3 (Valour)	1.8		1.8	*	0.30	
LSD (0.05)	0.1		0.1		0.14	
Nitrogen Rate					NS	
N1 (66%)	1.6	*	1.9		0.27	
N2 (100%)	1.6	*	1.9		0.28	
N3 (133%)	1.7		1.8	*	0.29	
LSD (0.05)	0.1		0.1		0.14	
Seed Rate						
1 (22)	1.8		1.7	*	0.45	
2 (47)	1.6	*	1.9	*	0.15	*
3 (67)	1.5	*	2.0		0.24	*
LSD (0.05)	0.1		0.1		0.14	
Seed Date			NS			
1 (Early)	1.8		1.9		0.42	
2 (Late)	1.5	*	1.9		0.14	*
LSD (0.05)	0.1		0.1		0.12	
RP	-		**		**	
CL	**		*		-	
NR	-		*		-	
CLxNR	-		-		-	
SR	**		**		**	
CLxSR	-		-		-	
NRxSR	-		-		-	
CLxNRxSR	-		-		-	
SD	**		-		**	
CLxSD	-		-		-	
NRxSD	-		-		-	
CLxNRxSD	-		-		-	
SRxSD	-		-		-	
CLxSRxSD	-		-		*	
NRxSRxSD	-		-		-	
CLxNRxSRxSD	-		-		-	

Table 6.9. Disease Evaluation - Saskatoon 2000.

	Early Leaf Lesions		Early Yellowing		Mottling		Pasmo		Uneven Maturity		Red Stem	
Cultivar			NS									
1 (McDuff)	1.17		0.06		1.76		1.83	*	0.85		1.48	*
2 (NorLin)	0.87	*	0.11		1.41	*	1.98	*	0.26	*	2.43	
3 (Valour)	0.91	*	0.11		1.63		2.39		0.31	*	1.07	*
LSD (0.05)	0.18		0.14		0.22		0.40		0.35		0.34	
Nitrogen Rate	NS		NS				NS		NS		NS	
N1 (66%)	1.02		0.11		1.54		1.98		0.52		1.59	
N2 (100%)	1.02		0.06		1.74		2.17		0.50		1.67	
N3 (133%)	0.91		0.11		1.52	*	2.17		0.41		1.72	
LSD (0.05)	0.18		0.14		0.22		0.39		0.35		0.34	
Seed Rate			NS		NS				NS			
1 (22)	0.87	*	0.07		1.63		1.84	*	0.65		2.17	
2 (47)	1.06		0.07		1.59		2.12		0.44		1.54	*
3 (67)	1.02		0.13		1.57		2.31		0.33		1.28	*
LSD (0.05)	0.18		0.14		0.22		0.39		0.35		0.34	
Seed Date	NS		NS		NS				NS			
1 (Early)	0.95		0.12		1.56		2.68		0.57		1.40	*
2 (Late)	1.01		0.06		1.64		1.34	*	0.38		1.93	
LSD (0.05)	0.14		0.11		0.18		0.32		0.28		0.28	
RP	**		-		**		**		*		**	
CL	*		-		*		*		*		**	
NR	-		-		*		-		-		-	
CLxNR	-		-		-		-		-		-	
SR	*		-		-		*		-		**	
CLxSR	-		-		-		*		*		-	
NRxSR	-		*		-		-		-		-	
CLxNRxSR	-		-		-		-		-		-	
SD	-		-		-		**		-		**	
CLxSD	-		-		-		-		-		-	
NRxSD	-		-		-		-		-		-	
CLxNRxSD	-		-		*		-		-		-	
SRxSD	-		-		-		-		-		-	
CLxSRxSD	-		-		-		-		*		-	
NRxSRxSD	-		-		-		-		-		*	
CLxNRxSRxSD	-		-		-		-		-		-	

Table 6.10. Disease Evaluation - Saskatoon 2001.

	Early Stand		Yellowing		Late Stand		Vigor	
Cultivar								
1 (McDuff)	1.9	*	2.2	*	1.3	*	3.1	
2 (NorLin)	2.2		2.5		1.4		3.0	*
3 (Valour)	1.9	*	2.2	*	1.4		3.1	
LSD (0.05)	0.3		0.3		0.1		0.1	
Nitrogen Rate								
N1 (66%)	1.9	*	2.6		1.3	*	3.0	*
N2 (100%)	2.0		2.4		1.3	*	3.0	*
N3 (133%)	2.2		2.0	*	1.4		3.1	
LSD (0.05)	0.3		0.3		0.1		0.1	
Seed Rate								
1 (22)	2.7		2.4		1.7		2.7	*
2 (47)	1.9	*	2.4		1.3	*	3.1	*
3 (67)	1.4	**	2.1	*	1.1	*	3.3	
LSD (0.05)	0.3		0.3		0.1		0.1	
Seed Date								
1 (Early)	2.2		2.2	*	1.4		3.0	*
2 (Late)	1.8	*	2.4		1.3	*	3.1	
LSD (0.05)	0.2		0.2		0.1		0.1	
RP	-		-		-		**	
CL	*		*		-		*	
NR	*		**		-		-	
CLxNR	-		-		-		-	
SR	**		*		**		**	
CLxSR	-		-		-		-	
NRxSR	-		-		-		-	
CLxNRxSR	-		-		-		-	
SD	**		-		*		*	
CLxSD	-		-		*		-	
NRxSD	-		-		-		-	
CLxNRxSD	-		-		-		-	
SRxSD	-		-		-		-	
CLxSRxSD	-		-		-		-	
NRxSRxSD	-		*		-		*	
CLxNRxSRxSD	-		-		-		-	

7.0 New Areas of Research

Weed Management:

-Early time of weed removal: The benefits of this approach have been well documented for field pea and canola. We need to look at the various herbicides currently registered in flax and determine which ones would be amenable in situations of early time of weed removal We should look at early applications just prior to when the seedling breaks the soil surface, at the cotyledon stage and at the 0.5", 1", 1.5" and 2" height of the seedling.

-Surface applications of granular herbicides: The merits of surface applications of granular ethylfluralins or trifluralins as a way to control some of the early weed flushes and the tolerance of flax to those methods of application.

Agronomy:

-Risk Area Maps for Flax: Development of risk area maps for flax production using the data collected from the yield formation study where we calculated growing degree days for different growth stages. We could determine time to maturity for different areas of western Canada as a function different seeding dates indicating the risks of delayed seeding for different areas in Western Canada. If we are to meet the growing demand for flax, the areas of production will have to expand.

-Characterizing flax establishment: Need to quantify the effects of soil temperature, soil moisture and seeding depth on the emergence of flax relative to canola.

-Yield Formation: Need to conduct more research on yield formation in flax in order to develop better selection tools for plant breeders.

-New Flax Ideotypes: Need to test flax lines that start flowering earlier, flower longer and branch more profusely. Need to look more closely at high yielding, late maturing lines and determine what can be done from an agronomic perspective to overcome the later maturity. A good starting point would be to play with seeding rates ie cultivars that can produce more bolls per unit area

-Soil types and Flax Production: Need to determine which soils are more conducive to good flax production relative to canola by focussing on soil quality attributes and soil texture.

-Seed Treatments and Foliar Fungicides: Need to look more closely at seed treatments and foliar fungicides and their impact on plant diseases and seed yield. Need to quantify the economic benefits.

-Flax and Canola Economic Models: Using the data from the flax x canola study, we need to develop economic models to quantify the risks and potential returns from growing these crops. For example, how much better is canola relative to flax in terms of net returns or is flax giving a better overall net return. This is important to know as we develop risk management tools for crop production.

-Advanced Plant Breeding Material: Need to look more closely at high yielding cultivars or advanced lines with late maturity and determine if we might be able to overcome lateness with manipulation of agronomic practises.

8.0 Appendices

Appendix 8.1. Summary of agronomic information for the study comparing flax and canola comparison for each year and location.

Year 1999

	Brandon	Indian Head	Saskatoon	Melfort[1]
Seeding Date #1	June 3,1999	May 8, 1999	May 8, 1999	May 6 (early), May 24 (late)
Seeding Date #2	June 15, 1999	May 26, 1999	May 24, 1999	May 24, 1999
Swathing Date #1 (Canola)	Sept 8	August 20, 1999	Sept 2	N/A
Swathing Date #2 (Canola)	N/A	August 21, 1999	Sept 13	N/A
Harvest Date (Flax) - 1	Sept 30	Sept 16	22 Sept.	N/A
Harvest Date (Flax) - 2	N/A	October 4, 1999	22 Sept.	N/A
Harvest Date (Canola) - 1	Sept 24	Sept 3	22 Sept.	N/A
Harvest Date (Canola) - 2	N/A	Sept 16	22 Sept.	N/A
Plant Counts (Spring)	June 23 and July 5	June 7 and June 24	14, 24 June	May 28 (early), June 15 (late)
Flax Variety	CDC Normandy	CDC Normandy	Normandy	Normandy
Canola Variety	Quantum	Quantum	Quantum	Quantum
Seeding Rate (kg/ha) - Flax	40	63	44.8	56
Seeding Rate (kg/ha) - Canola	6	6.7	5.68	7
Soil Fertility (Soil Test Levels)				
Nitrogen (kg/ha) NO_3-N 0-24"	76	62.7	48	55
Phosphorus (kg/ha) PO_4-P 0-6"	60	20.1	32	18
Potassium (kg/ha) K 0-6"	800	571	606	468
Sulfur (kg/ha) SO_4-S	100	93	23	101
Soil Fertility - Recommended -Flax				
Nitrogen (kg/ha) N	130	101	67	50
Phosphorus (kg/ha) P_2O_5	0	28	30	25
Potassium (kg/ha) K	0	14	8.5	0
Sulfur (kg/ha) S	0	14	0	0
Soil Fertility - Recommended - Canola				

Nitrogen (kg/ha) N	130	101	100	85
Phosphorus (kg/ha) P_2O_5	0	28	30	25
Potassium (kg/ha) K	0	14	8.5	0
Sulfur (kg/ha) S	0	14	14	10
Weed Control				
Fall Application (Product, Date, Rate)	none	none	Reglone Sept 13 0.8 L/ha	N/A
Pr-Seeding (Product, Date, Rate)	Fortress; 13.6lbs/A	Edge - Apr 26 - 1130 g ai/ha (canola) Fortress - Apr 26 - 2023 g ai/ha (flax) Round-Up - May 7 - 890 g ai/ha	-	Roundup; May 6; 1.0 L/ac
In-Crop (Product, Date, Rate)	none	Flax - Poast Flax Max - 1166 g ai/ha - June 4 and June 24 Canola - Muster Gold 6 g ai/ha - June 15 and June 21 Canola - Poast and Lontrel 394 g ai/ha - June 15 and June 24	Select June 4-0.37 l/ha July 6- 0.081 L/ha Basagran June 7- 2.24 L/ha	Buctril-M; June 9 (1st flax), June 16 (2nd flax); 0.45 L/ac Muster; June 11 (1st canola), June 16 (2nd canola); 12 g/ac Lontrel; June 11 (1st canola), June 16 (2nd canola); 0.25 L/ac Poast; June 18 (all flax & canola); 0.45 L/ac
Seeder Model and Row Spacing	Conserva-Pak 9"	Conserva-Pak 12"	Fabro Seeder 17.5cm	Conserva-Pak 9"

[1] The data was lost due to a misapplication of herbicide.

Year: 2000

	Brandon	Indian Head	Saskatoon	Melfort
Seeding Date 1	May 4, 2000	May 2, 2000	May 8, 2000	36650
Seeding Date 2	May 26, 2000	May 23, 2000	May 19, 2000	36668
Swathing Date 1 (Canola)	August 11, 2000	August 15, 2000	August 25, 2000	36768
Swathing Date 2 (Canola)	August 23, 2000	August 15, 2000	August 25, 2000	36768
Harvest Date (Flax) - 1	Sept 29	Sept 13	Sept 27	36808
Harvest Date (Flax) - 2	Sept 29	Sept 13	Sept 27	36808
Harvest Date (Canola) - 1	August 29, 2000	August 29, 2000	Sept 12	36800
Harvest Date (Canola) - 2	Sept 1	August 29, 2000	Sept 12	36800
Plant Counts (Spring)	June 8 June 16	June 7 and June 13	June 2 June 19	May 29 & June 3
Flax Variety	CDC Normandy	CDC Normandy	CDC Normandy	CDC Normandy
Canola Variety	Quantum	Quantum	Quantum	Quantum
Seeding Rate (kg/ha) - Flax	45	63	45	56 kg/ha
Seeding Rate (kg/ha) - Canola	6	6.7	5.7	7 kg/ha + Counter 5G @ 7 kg/ha
Soil Fertility (Soil Test Levels)				
Nitrogen (kg/ha) NO_3-N 0-24"	48	13	50.5	47
Phosphorus (kg/ha) PO_4-P 0-6"	66	10	28	22
Potassium (kg/ha) K 0-6"	1654	554	572.5	570
Sulfur (kg/ha) SO_4-S	160+	16	68.5	59
Soil Fertility - Recommended -Flax				
Nitrogen (kg/ha) N	60	110	62	50
Phosphorus (kg/ha) P_2O_5	0	50	34	30
Potassium (kg/ha) K	0	20	17	
Sulfur (kg/ha) S	0	20	11	10
Soil Fertility - Recommended - Canola				
Nitrogen (kg/ha) N	60	130	84	85
Phosphorus (kg/ha) P_2O_5	0	50	34	30

Potassium (kg/ha) K	0	20	17	25
Sulfur (kg/ha) S	0	20	28	
Weed Control				
Fall Application (Product, Date, Rate)	none	Fortress (Flax) Oct 30 2373 g ai/ha Edge (Canola) Oct 30 350 g ai/ha	none	none
Pr-Seeding (Product, Date, Rate)	Roundup May 6, early May 20 late 1.0 L/ac	Round-up May 4 879 g ai/ha	-	Roundup May 6 0.75 L/ac in 35 L H2O
In-Crop (Product, Date, Rate) - Flax	Poast 0.45 l/ac & Lontrel 0.25 L/ac June 3 early seeding June 23 Late seeding	Poast Flax Max 879 g ai/ha on June 7 and 27	Lontrel June 2 & 19 .26 l/ha Buctril M (flax) June 27 .2 l/ha	Poast Ultra June 5 0.2 L/ac in 45 L H2O(both crops) Basagran June 21 0.91 L/ac in 90 L H2O(flax) Roundup August 29-canola & Sept 13-flax 1 L/ac in 45 L H2O
In-Crop (Product, Date, Rate) -Canola		Poast and Lontrel 394 g ai/ha June 15 and 24	Muster & Select (canola) June 27 .2 l/ha	Poast Ultra June 19 0.2 L/ac in 45 L H2O Muster June 19 12 g/ac in 45 L H2O(canola) Ronilan July 14 0.4 kg/ac(canola
Seeder Model and Row Spacing	Conservapak 9"	Conservapak - 12"	9" Conservapak	9" Conservapak

Year: 2001

	Brandon	Indian Head	Saskatoon	Melfort
Seeding Date 1	May 14, 2001	May 7, 2001	May 4, 2001	May 3, 2001
Seeding Date 2	May 29, 2001	May 28, 2001	May 17, 2001	May 17, 2001
Swathing Date 1 (Canola)	Aug 14(Can) Aug 21(Flax).	August 20, 2001	N/A	August 22, 2001
Swathing Date 2 (Canola)	Aug 22(Can); didnt do flax	August 20, 2001	N/A	August 22, 2001
Harvest Date (Flax) - 1	August 31, 2001	Sept 24	Sept 6	Sept 18
Harvest Date (Flax) - 2	Sept. 19	Sept 24	Sept 6	Sept 18
Harvest Date (Canola) - 1	August 22, 2001	August 28, 2001	August 20, 2001	Sept 5
Harvest Date (Canola) - 2	August 31, 2001	August 28, 2001	August 27, 2001	Sept 5
Plant Counts (Spring) (Date)	June 4(Early); July 3(Late).	June 15, 2001	June 5, 18	May 28, 2001
Flax Variety	CDC Bethune	CDC Bethune	CDC Bethune	CDC Bethune
Canola Variety	InVigor 2663	InVigor 2663	Invigor 2663	Invigor 2663
Seeding Rate (kg/ha) - Flax	45	56	45	56
Seeding Rate (kg/ha) - Canola	6	5.4	5.7	7
Soil Fertility (Soil Test Levels)				
Nitrogen (kg/ha) NO_3-N 0-24"	27	55	24.6	42
Phosphorus (kg/ha) PO_4-P 0-6"	15.2	22	19	16
Potassium (kg/ha) K 0-6"	577.5	571	1142	464
Sulfur (kg/ha) SO_4-S	60.7	74	45.9	99
Soil Fertility - Recommended -Flax	This is what we applied(100%)			
Nitrogen (kg/ha) N	90	101	72.8	50
Phosphorus (kg/ha) P_2O_5	34.8	20	39.2	30
Potassium (kg/ha) K	0	15	0	0
Sulfur (kg/ha) S	15.7	15	0	0

Soil Fertility - Recommended - Canola	This is what we applied(100%)			
Nitrogen (kg/ha) N	90	123	70-75	80
Phosphorus (kg/ha) P_2O_5	34.8	30	30-40	30
Potassium (kg/ha) K	0	15	0	0
Sulfur (kg/ha) S	15.7	15	0	20
Weed Control				
Fall Application (Product, Date, Rate)	n/a	Canola - Edge Oct 17 - 1413 gai/ha Flax - Fortress Oct 17 - 2408 gai/ha	n/a	none
Pr-Seeding (Product, Date, Rate)	n/a	Round-Up May 8 900 gai/ha	n/a	none
In-Crop (Product, Date, Rate)	Canola- Liberty;June 17;1.35L/acre Flax- Select;June 17;0.08L/acre. Lontrel (0.16L/acre) &MCPA Ester(0.3 L/acre ;June 17	Canola & Flax- Lontrel 153 gai/ha June 11 & Select June 20 48 gai/ha Flax - FlaxMax June 28 503 gai/ha Canola - Lontrel	Flax Buctril M June 13 (1L/ha) Select (with Amigo) June 13 (0.197L/ha) Canola Muster June 15 (19.7g/ha) Select (with Amigo) June 15 (0.197g/ha)	Roundup; May 10 0.5L/ac (All)Poast Ultra June 14 0.20L/ac (flax) Buctril M June 14; 0.405L/ac (flax) Poast UltraJune 12 0.20L/ac (canola) Lontrel June 12 0.17L/ac (canola) Muster June 12 8g/ac (canola)
Seeder Model and Row Spacing	Conserva-Pak; 9"(23cm); 16 runs.	Conserva-Pak - 12"	20.3cm	Conserva-pak 9"

Appendix 8.2 Summary of agronomic information for the study looking at yield formation in flax.

Year: 1999

	Morden	Brandon	Indian Head	Saskatoon	Melfort
Seeding Date 1	May 17, 1999	June 3, 1999	May 8, 1999	May 8	May 7, 1999
Seeding Date 2	May 27, 1999	June 15, 1999	May 26, 1999	May 24, 1999	May 24, 1999
Harvest Date - Date 1	Sept 5	October 6, 1999	Sept 16	22 Sept.	Oct 10 (reps 1,2), Oct 11 (rep 3)
Harvest Date - Date 2	Sept 5	October 15, 1999	October 4, 1999	22 Sept.	Oct 10 (reps 1,2), Oct 11 (rep 3)
Collection date for Boll Counts	August 26, 1999	Sept 15	August 18, 1999	19Aug., 13Sept.	August 16, 1999
Plant Counts (Spring) - Date 1	June 10, 1999	June 23, 1999	June 7, 1999	June 14, 1999	May 28, 1999
Plant Counts (Spring) - Date 2	June 17, 1999	July 5, 1999	June 24, 1999	June 24, 1999	June 15, 1999
Flax Variety #1	McDuff	AC McDuff	CDC Valour	Norlin	Valour
" #2	NorLin	Norlin	AC McDuff	AC McDuff	McDuff
" #3	Valour	CDC Valour	CDC Normandy	CDC Valour	Norlin
Soil Fertility (Soil Test Levels)					
Nitrogen (kg/ha) NO_3-N 0-24"	40	76	52.6	48	67
Phosphorus (kg/ha) PO_4-P 0-6"	72	60	16.8	32	19
Potassium (kg/ha) K 0-6"	1344	800	571	606	468
Sulfur (kg/ha) SO_4-S	78	-	83	23	97
Soil Fertility - Recommended					
Nitrogen (kg/ha) N	76	60	90	67	50
Phosphorus (kg/ha) P_2O_5	15	0	28	15	25
Potassium (kg/ha) K	0	0	14	8.5	0
Sulfur (kg/ha) S	19	-	14	0	0

Weed Control					
Fall Application (Product, Date, Rate)	Sept 21/98 Roundup 0.5 + 2,4-D 0.9 L/acre + AgSurf	none	none	Reglone Sept 13 0.8 L/ha	none
Pr-Seeding (Product, Date, Rate)	May14 Roundup 0.5 L/acre + AgSurf	Treflan QR5;June 2;20.4lbs/Ac	Fortress - April 26 - 2023 g ai/ha Round-Up - May 7 - 890 g ai/ha	None	Roundup; May 6; 1.0 L/ac
In-Crop (Product, Date, Rate)	June15 Poast 0.2 L/acre + Merge June23 Basagran 0.7 L/acre + Assist	Buctril M Poast/Merge June 20(early) 0.4L/A/0.45L /A/0.4L/A. Buctril M Poast Merge; July 6 (all of test) 0.4L/A/0.45L /A/).4L/A	Poast Flax Max - 1166 g ai/ha - June 4 Poast Flax Max - 1166 g ai/ha - June 24	Select June 4-0.37 l/ha July 6- 0.081 L/ha Basagran June 7- 2.24 L/ha	Buctril-M; June 9 (early), June 16 (late); 0.405 L/ac Poast; June 18; 0.45 L/ac
Seeder Model and Row Spacing	0-Till disc drill (Ben Dyck/ Fabro) 25cm spacing	ERDA disc- 30cm; fertilizer 8 cm beside seed	Conserva-Pak - 12"	17.5 cm	Conserva-Pak 9"

Year: 2000

	Morden	Brandon	Indian Head	Saskatoon	Melfort
Seeding Date 1	May 2	May 4, 2000	May 2, 2000	May 5, 2000	May 7, 2000
Seeding Date 2	May 19, 2000	May 26, 2000	May 23, 2000	May 19, 2000	May 23, 2000
Harvest Date - Date 1	Aug. 22	Sept 27	Sept. 13	Sept 25	October 3
Harvest Date - Date 2	Sept. 12	Sept 27	Sept .13	Sept 25	October 3
Collection date for Boll Counts	Aug 2-20	Aug 15 Aug 29	Aug. 16	Aug 7 Sept 4	August 14, 2000
Plant Counts (Spring) - Date 1	June 2, 2000	June 8, 2000	May 30, 2000	June 1, 2000	May 29, 2000
Plant Counts (Spring) - Date 2	June 9, 2000	June 16, 2000	June 13, 2000	June 19, 2000	June 4, 2000
Flax Variety #1	McDuff	CDC Valor	CDC Valour	AC McDuff	CDC Valour
" #2	NorLin	AC McDuff	AC McDuff	Norlin	AC McDuff
" #3	Valour	Norlin	Norlin	CDC Valour	Norlin
Soil Fertility (Soil Test Levels)					
Nitrogen (kg/ha) NO_3-N 0-24"	27	48	15	50.5	51
Phosphorus (kg/ha) PO_4-P 0-6"	43	66	15	28	24
Potassium (kg/ha) K 0-6"	1129	1654	563	572.5	570
Sulfur (kg/ha) SO_4-S (0-24")	170	160+	22	68.5	74
Soil Fertility - Recommended					
Nitrogen (kg/ha) N	95	60	110	62	50
Phosphorus (kg/ha) P_2O_5	17	0	40	34	30
Potassium (kg/ha) K	0	0	17	17	
Sulfur (kg/ha) S	0	0	17	11	
Weed Control					
Fall Application (Product, Date, Rate)	Roundup1.0 L/acre + 2,4-D 0.9 L/acre Oct 7	none	Fortress - Oct.30/99 2374 gai/ha		Roundup Sept 13 1 L/ac in 45 L H2O

Pr-Seeding (Product, Date, Rate)	Poast 0.2 L/acre + Merge May 5	Roundup 1.0 l/ac Early May 6 Late May 20,	Round-up May 4 879.3 g ai/ha	-	Roundup May 6 0.75 L/ac in 45 L H2O
In-Crop (Product, Date, Rate)	- Basagran 0.2 L/acre + Assist June8 - Poast 0.3 L/acre + Merge June20	Poast 0.45 L/ac May 25 & June 3 entire test Poast 0.45 l/ac & Lontrel 0.25 L/ac June 15 Early date June 23 Late seeding	Poast Flax Max - June 7 and 24, 871 g ai/ha	Lontrel June 2 & 19 .26 l/ha Buctril M June 27 .2 l/ha	Poast Ultra June 5 0.2 L/ac in 45 L H2O Basagran June 21 0.91 L/ac in 90 L H2O
Seeder Model and Row Spacing	disc drill (Ben Dyck/ Fabro) 25cm spacing	Fabro 12"	Conserva-Pak 12"	ConservaPak 9"	9" Conserva-Pak

Year: 2001

	Morden	Brandon	Indian Head	Saskatoon	Melfort
Seeding Date 1	May 14, 2001	May 12, 2001	May 7, 2001	May 4, 2001	May 2, 2001
Seeding Date 2	May 29, 2001	June 1, 2001	May 28, 2001	May 17, 2001	May 17, 2001
Harvest Date - Date 1	Sept. 5	August 31, 2001	Sept 24	Sept 6 & 7	Sept 17
Harvest Date - Date 2	Sept. 5	September 17, 2001	Sept 24	Sept 6 & 7	Sept 17
Collection date for Boll Counts Date 1 Date 2	Aug. 15-21 Aug. 27-31	Aug 31-Early; Sept 4-Late	Aug 21 Aug 21	Aug 5 Aug 5	Aug 7 Aug 7
Plant Counts (Spring) - Date 1	June 11, 2001	May 29 & June 1	June 19, 2001	June 5, 2001	May 28, 2001
Plant Counts (Spring) - Date 2	June 20, 2001	June 22, 2001	June 19, 2001	June 18, 2001	May 28, 2001
Flax Variety #1	McDuff	CDC Valour	CDC Valour	AC McDuff	CDC Valour
" #2	NorLin	Norlin	Ac McDuff	Norlin	AC McDuff
" #3	Valour	AC McDuff	Norlin	CDC Valour	Norlin
Soil Fertility (Soil Test Levels)					
Nitrogen (kg/ha) NO_3-N 0-24"	48	27	43	25	47
Phosphorus (kg/ha) PO_4-P 0-6"	91	15	35	19	17
Potassium (kg/ha) K 0-6"	1118	578	572	1142	491
Sulfur (kg/ha) SO_4-S	60	61	91	46	84
Soil Fertility - Recommended					
Nitrogen (kg/ha) N	69	101	101	73	50
Phosphorus (kg/ha) P_2O_5	19	26	20	39	30
Potassium (kg/ha) K	0	0	10	0	0
Sulfur (kg/ha) S	42	15	10	0	0
Weed Control					

Fall Application (Product, Date, Rate)	Roundup 1.0 L/acre + 2,4-D 0.9 L/acre Sept.25	n/a	Fortress - Oct 17/00 2408 gai/ha	N/A	none
Pr-Seeding (Product, Date, Rate)	Roundup1.0 L/acre May 3	Vantage; May 11; 0.5L/acre	Round-Up - May 8 900 gai/ha	N/A	none
In-Crop (Product, Date, Rate)	Poast Ultra 0.2 L/acre May29, June25 Basagran 0.9 L/acre June 21	Select; June17; 0.08L/acre. MCPA Ester;0.3L/acre&Lontrel 0.16L/acre; June 17.	Lontrel June 11 153 gai/ha Select June 20 - 48 gai/ha FlaxMax June 28 - 503 gai/ha	Buctril M June 13 (1L/ha) Select (with Amigo) June 13 (0.197L/ha)	Roundup; May 10 0.5L/ac Poast Ultra June 14 0.20L/ac Buctril M June 14 0.405L/ac
Seeder Model and Row Spacing	Disc drill 25cm (Fabro/ Ben Dyck)	ERDA; 12"(30cm).	Conserva-Pak 12"	20.3cm	Conserva-pak 9"