Field Plot Conditions for the Expression and Selection of Straw Fibre Concentration in Oilseed Flax.

A Thesis

Submitted to the Faculty of Graduate Studies and Research

in Partial Fulfillment of the Requirements

For the Degree of

Master of Science

in the

Department of Plant Sciences

University of Saskatchewan

Saskatoon, Saskatchewan

Canada

by

Alison Burton

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Abstract:

In Canada, flax (*Linum usitatissimum* L.) is grown for its seed oil. However, a major disadvantage associated with growing oilseed flax is that the straw is difficult to incorporate into the soil after harvest. Instead, the majority of flax straw is burned in the field, increasing the workload for farmers, as well as creating air pollution. Agronomic concerns are also associated with burning, since it leaves fields vulnerable to wind and water erosion. A small market exists for Canadian flax straw for making high quality paper products and some plastic composites. However, fibre-based and fibre-using industries are growing world wide, and flax straw fibre is becoming an important product. Flax straw fibre concentration varies among cultivars and environments. Consistently high fibre concentrations are essential if the fibre in oilseed flax is to become an important product for Canadian farmers. This study assembled the agronomic information necessary to select for increased straw fibre concentration in the Crop Development Centre (CDC) Flax Breeding Program. Three experiments were conducted to determine: how seeding rate and row spacing effects straw fibre concentration, the effects of seeding date on straw fibre concentration, and how nitrogen fertilizer rates effects straw fibre concentration. Seeding in mid-May at either an 18 or 36 cm row spacing at a seeding rate of 30 or 45 kg/ha resulted in high straw fibre concentration without reducing other important oilseed characteristics such as seed yield, oil content and straw fibre yield. Nitrogen fertilizer did not have an effect on either straw fibre concentration or straw fibre yield.

Acknowledgments:

I would like to extend a sincere, heartfelt thank you to my supervisor Dr. G. Rowland, who has helped me immensely with his patience, words of wisdom, friendship and guidance throughout my time at the University of Saskatchewan. I would also like to thank the other members of my committee, Drs. B.E. Coulman (Chair), G.R. Hughes, F.A. Holm, and S.J. Shirtliffe for their valuable contributions to this research. Financial support from the Saskatchewan Flax Development Commission and the National Sciences and Engineering Research Council is acknowledged and greatly appreciated.

I would also like to extend my thanks to Mr. Gary Farkas, Mrs. Barb Boon, and the Flax Crew at the Kernen Crop Research Farm for all of their support, time and effort. Thanks to Mr. Doug Hassard for sharing his technical knowledge of the NIR instrument, as well as Mr. Randy Cowan, and Mr. Alvin Ulrich from Biolin for their assistance as well.

Finally I would like to genuinely thank my family and close friends for their enduring support and encouragement throughout this experience. I dedicate this work to my Grandad, who I know is looking down on me and smiling.

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1.0 Introduction:

In Canada, oilseed flax (*Linum usitatissimum* L.) is grown primarily for the oil that is produced in its seed. A high content of linolenic acid in linseed oil makes it a good drying oil because it oxidizes rapidly (Diepenbrock and Pörksen, 1993). The oil is used mostly for industrial purposes such as the manufacturing of paints and flooring. However, there is increasing demand for flaxseed and its components in human and animal health products because of its high linolenic acid (omega-3) levels. The majority of flax grown in Canada is produced in Saskatchewan (SAFRR, 2004).

A major problem for oilseed flax producers is dealing with the fibrous straw (Ulrich and Braun, 2000). Flax is considered to be a bast fibre plant, and these fibres are produced in bundles in the cortical region of the stem between the outer cuticle and inner woody core tissues (Akin, 2005, Akin et al., 2005). The fibre in the stem prevents farmers from easily incorporating flax straw into the soil after harvest. Two factors are responsible for this. These long, tough stem fibres plug machinery and the fibre is slow to degrade in the soil. This can result in straw bunching in the field during subsequent tillage operations.

There are three management practices presently used by farmers to deal with flax straw; spreading, burning, or baling. Flax residue (either chopped straw, or straw left intact) is spread over fields at harvest but is often spread unevenly. This results in variable surface soil temperatures and moisture content throughout the field (SAFRR, 2004). These differing conditions effect the germination and maturity of subsequent crops grown on flax stubble. As well, the cutting height and straw moisture content at harvest, can further complicate this practice since moist straw is very difficult to cut and chop (SAFRR, 2004).

Instead of struggling to incorporate flax straw back into the soil or have it chopped and spread, most of flax residue is burned in the field (Ulrich and Braun, 2000, SAFRR, 2004). This creates air pollution, which is becoming an increasing concern with regards to people's health and the environment. Lobbying for legislation to stop agricultural residue burning has occurred (Ulrich and Braun, 2000). Saskatchewan Agriculture and Food and other organizations are working towards the reduction of residue burning. Agronomic concerns are also associated with burning flax residue in fields, as it leaves fields vulnerable to wind and water erosion.

The third option is baling to sell the straw to a processor or other uses such as golf courses. However, there are limited markets for the straw, so this is not a viable option for many farmers.

The utilization of fibre from the straw of oilseed flax is increasing. Many products can be manufactured using oilseed flax fibres and there is an established market for using flax fibres in specialty paper products. Textiles, insulation, geotextiles, plastic composites, particle board, components in building materials, and horticultural applications are some old and new products that utilize straw fibre (SAFRR, 2004, Rennebaum et al., 2002, Dimmock et al., 2005).

Europe has been the driving force behind the creation of innovative ways to use flax straw fibre. However, in Europe straw fibres are usually harvested from fibre flax instead of oilseed cultivars. Even though fibre flax and oilseed flax are the same species, they have different morphologies, and are grown as two commercially distinct crops (Foster et al., 1998). Oilseed flax is grown for the seed, and fibre flax is grown for the fibre in the straw. The plant type and production system for fibre flax are different than that of the oilseed cultivars grown in Canada, leading to different fibre properties (SAFRR, 2004). Since oilseed flax plants are naturally shorter than those of fibre flax, they inherently produce shorter fibres. These new applications of flax fibre mentioned above do not require the very long and fine fibres found in fibre flax. Therefore oilseed flax fibre could be used, creating the potential for a dual-purpose crop (Foster et al., 1998). This would result in additional income for farmers, and eliminate the concerns associated with burning flax residue.

Preliminary tests conducted in Saskatchewan have shown that the amount of fibre fluctuates between cultivars, but it is unclear which oilseed cultivar consistently yields the highest straw fibre concentration when grown in western Canada.

To make processing of oilseed flax straw economical and to expand the industry, a consistently high concentration of fibre in oilseed flax straw is needed. As well, a fast, easy, and reliable method of determining flax straw fibre concentration is required

(Barton et al., 2002). Near-Infrared Spectroscopy (NIR) now allows for this estimation to be made from a small sample of mature straw.

The Crop Development Centre (CDC) Flax Breeding Program at the University of Saskatchewan is attempting to increase straw fibre concentration. In this program, the segregating generations (F_3-F_6) are grown in 3m long rows with 30 cm spacing between rows. This allows for easy weeding, selection of plants, and harvesting of single rows with a Japanese rice harvester. Since the seed of a single plant is the source for each row, the seeding rate is variable. For yield trials which occur from the F_6 generation onward the seeding rate is constant and the plot size increases to multiple rows with a narrower row spacing of 15 cm. The seeding of all these trials usually begins with the yield tests in mid-May and finishes with the nurseries in late May to early June. It is not understood what the effects of planting density (row spacing and seeding rate) and seeding date have on stem fibre concentration in oilseed flax, and consequently on the ability of plant breeders to select for this trait.

The primary objective of this study was to determine the effects of agronomic practices used in the CDC Flax Breeding Program on oilseed flax straw fibre concentration. This will serve to pinpoint the optimal conditions for identifying and selecting for straw fibre concentration and will help develop the protocol required for the measurement of fibre using the NIR. The agronomic practices examined in this study were seeding rate, row spacing, seeding date, and nitrogen fertilizer application. It may also suggest future experiments to develop appropriate practices for farm conditions.

2.0 Literature Review:

2.1 Flax

2.1.1 History and Origins

Flax originated in the Near East about 10,000 years ago (Allaby et al., 2005) and spread from the Near East to Europe, the Mediterranean, central and western Asia, and the Abyssinian regions. Flax came to North America approximately four hundred years ago, when it was brought to New France in 1617 by Louis Hébert, the first farmer in Canada (Flax Council of Canada, 2006).

Flax is an annual crop belonging to the family Linaceae that has been bred to suit two different needs: it can be grown either for its seed oil (known as linseed), or straw fibre (fibre flax). Both crops have been derived from the same species, *Linum usitatissimum*, through selection for different traits. Fibre flax is generally taller with less basal branching than oilseed flax in order to maximize fibre length in the straw, but with the consequence of reduced seed yield.

2.1.2 Botany

Flax is a diploid (2n=30), highly self-pollinating species with perfect, complete and pedicellate flowers (Freer, 1991, Turner, 1987). Flax flower parts: petals, sepals and stamens all occur in units of 5 (Turner, 1987). The ovary has 5 carpels each of which is capable of developing 2 seeds, for a maximum of 10 seeds per boll (capsule). Petal colour can range from dark to light blue, or may be pale pink or white. In the field, flowers open shortly after sunrise, and the petals drop by the late afternoon (Freer, 1991). Some cross-pollination facilitated by insects occurs at very low levels.

Flax seeds are flat, usually shiny and quite slippery, oval in shape, and are pointed at the embryo axis end. Seed colour varies among cultivars, and can range from light to dark brown or yellow.

Generally the average life cycle of a flax plant in western Canada is 100 days. The first half of the cycle is known as the vegetative stage, and the latter half is made up of the flowering and maturation periods.

Fibres found in the cortical region of flax stems between the outer cuticle and the inner woody core tissues are made up of long multinucleate cells without septa, and originate from procambial cells in the protophloem (Akin, 2005, Morvan et al., 2003).

These fibre cells are very long, and have thick secondary walls (Morvan et al., 2003). The cells are arranged in bundles numbering from one to three dozen cells that circle the vascular cylinder. There are two main steps in fibre development: cell elongation and the thickening of secondary walls. Fibre cell elongation occurs at the top of the stem, and fibre length is related to that of the internode. The majority of the secondary wall deposits occur after flowering and fill the fibre during the maturation of the capsule. Flax fibres have low elasticity and high tensile strength, and so provide mechanical support to the stem as well as protection against insects.

2.1.3 Areas of Production

Canada is the world's largest producer of oilseed flax, with Saskatchewan producing about 80% of the flax grown in western Canada in 2005 (Flax Council of Canada, 2006). In the United States, oilseed flax is predominantly grown in North Dakota and Minnesota. Flax is also produced for its seed as well as for its fibre throughout Europe, India, China, and Australia (Morvan et al., 2003).

2.1.4 Utilization

Oilseed flax is the crop that is grown commercially in Canada. The oil crushed from the seeds can either be used for industrial or edible purposes, depending on the fatty acid composition (Flax Council of Canada, 2006). Since flaxseed oil contains more than 50% α-linolenic acid, it is well suited for industrial use in protective coatings such as varnishes, paints, stains and lacquers. An important product also made from flaxseed oil is linoleum flooring, which is durable, long-lasting, and biodegradable. Furthermore, flaxseed oil is a component in other products such as soaps, automotive brake linings, and printer's ink. There is also a yellow-seeded flax, which is called solin, and has a low level of linolenic acid (DeClercq, 2004). Oil from solin cultivars contains less than 5% α-linolenic acid, making it suitable for use as a cooking or salad oil.

Other products can be made from linseed meal, which is a by-product of the seed and contains approximately 36% crude protein. It is therefore a good protein supplement in livestock feed (Flax Council of Canada, 2006). Linseed meal is high in soluble fibres, and so helps aid in digestion (Green, 1995). The unique combination of amino acids in flax seeds has also been found to improve the coat of animals, and so has become a popular additive to horse feed since it produces a glossy coat important to horse breeders.

There is a growing trend of human consumption of flaxseed as people are becoming more health-conscious. There are many human health benefits associated with flaxseed, such as the laxative effect of the soluble fibre (Green, 1995). In addition, the fatty acid composition of flaxseed oil is very beneficial, since it contains a large amount of omega-3 fatty acids (α -linolenic acid at approximately 55% of the oil) which are essential to the human diet (Green, 1995, Berglund, 2002). Omega-3 fatty acids have potentially life-saving benefits, such as helping prevent heart disease, as well as preventing some types of cancer. Flaxseeds are the richest source of lignans in food grains (Green, 1995). Lignans are possible anti-carcinogenic compounds, and are associated with reducing the risk of heart disease (Green, 1995, Berglund, 2002). Flaxseeds are used in many food products, such as baked goods and breakfast cereals.

2.1.5 Uses for flax straw fibre

Many products can be manufactured using oilseed flax fibres, and there is an established market for flax fibres in specialty paper products. Composite materials, textiles, automotive components, insulation, geotextiles, plastic composites, particle board, components in building materials, pollution filters, and horticultural applications are a range of some of the old and new products that utilize straw fibre (Norton et al. 2006, Dimmock et al., 2005, SAFRR, 2004, Rennebaum et al., 2002, Foster et al., 2000).

Using natural fibres such as flax fibre as a replacement for fibreglass is also of major interest (Akin et al., 2005), and has a market in the automotive industry. Flax fibres have lower density (Kessler and Kohler, 1996), sound absorbance, and lower shatter properties than fibreglass (Akin et al., 2005). Another advantage is that composites made from flax fibres have lower manufacturing energy costs, about 80% less than fibreglass. Composite material is strengthened by the addition of flax straw as it reinforces the matrix (Norton et al., 2006). As well, it has been proposed that insulation made from flax fibre will replace fibreglass (Ulrich and Braun, 2000).

Cottonized flax (textile blends of cotton and flax fibres) is garnering interest because of the problems associated with cotton production. Cotton is restricted to sub-tropical climates and requires high water and nutrient inputs to ensure good yields (Ebskamp, 2002). This new blended textile also has a few advantages over regular cotton, as the blend of flax fibres and cotton leads to a more breathable fabric, which provides good thermal insulation. These are two features that add to the value of the blended textile.

2.2 Factors Influencing Fibre Content in Oilseed Flax

Many factors may effect the concentration and quality of fibre found in oilseed flax straw. A consistently high straw fibre concentration is required for the harvest of fibre from oilseed flax to be economically viable. Factors influencing straw fibre concentration in oilseed flax need to be studied in order to optimize the conditions for the expression and selection of fibre, and eventually to manage flax straw in farm fields.

2.2.1 Weather

Weather in western Canada is quite variable, and frost or drought can harm flax development (Foulk et al, 2004). This complex factor, combined with differing agronomic practices and cultivars, results in oilseed flax straw that has a range of fiber contents (SaskFlax, 2002). Research conducted in Saskatchewan has shown that fibre content of oilseed flax straw grown in the province ranges from 2% to 30% in the same year depending on the weather, cultivar and agronomic practices. Dimmock et al. (2005) found that environment was a major contributor to variation in flax fibre yields over a two year trial. Some cultivars showed better stability than others. Taylor and Morrice (1991) found that year and location influence seed yields of flax more than different agronomic practices. Norton et al. (2006) obtained similar results, since they found that variation between years was greater than the variation between cultivars for both fibre fineness and strength. Sankari (2000) concurs, stating that precipitation and temperature differences over a two year study caused a wide variation in oilseed flax cultivars on mean plant stand density, mean plant height, mean stem yield, as well as mean seed yield.

It has been hypothesized that temperature has a large impact on yield via its effect on the rate of development and so on the period of growth (Casa et al., 1999). High temperatures during the ripening stage have been shown to reduce the number of seeds per capsule as well as seed weight, and decrease oil yield and quality. As well, dry weather during development results in poorly filled seed (McGregor, 1964). Low temperatures during the period of development could slow the growth of the plant, and so extend the growing period. Sankari (2000) suggests that sufficient water supply after plant establishment and before flowering may be beneficial for maximum height of the stands, since that is the period of greatest stem elongation. Rainfall late in the season could result in the growth of new tillers and leaves, which would cause uneven ripening (Casa et al., 1999).

Flax can be grown on a range of soil types, but does best on well-drained medium to heavy textured soils (Casa et al., 1999, Hocking et al., 1987). Silty or clay loams with pH about 6 are best. Ideal weather conditions during the growing season for flax would consist of adequate water supply during the growth stages, and good drying weather during flowering and ripening (Sheppard and Bates, 1988).

2.2.2 Oilseed Flax Cultivars

Preliminary tests have been conducted throughout Saskatchewan to investigate the fibre concentration in different flax cultivars (SAFRR, 2004). Averaged over four locations, CDC Gold had an NIR fibre content based on unretted straw of 16.3% (personal communication, Biolin Research Inc, 2003). Nine flax cultivars were tested at five locations, giving a range of average straw fibre percent from 11.8% to 15.1%. The solin cultivar, SP 2090, had a fibre concentration of 15.1%, while the flax cultivar CDC Mons had the lowest average straw fibre percent of 11.8%. AC Hanley had an average fibre concentration of 14.5%, Prairie Blue had 14%, and CDC Bethune had 12.7%. Fibre concentration was not consistent amongst oilseed flax cultivars. It is still unclear as to which oilseed cultivar has the potential to consistently yield the highest straw fibre concentration when grown in western Canada.

2.2.3 Seeding Rates

Rowland (1980) found that increased seeding rates corresponded with increased straw yields. Foulk et al. (2004) also found that dry plant yield was generally increased by a higher seeding rate. Easson and Cooper (2002) found that a reduction in seeding rate decreased straw yield, and the proportion of fibre in the straw. Sankari (2000) agreed with this, stating that dense seeding rates resulted in high stem yield relative to seed yield.

Higher plant populations have been proposed to increase straw fibre content since there would be more plants per unit area, resulting in thinner individual stems (SAFRR, 2004, Booth et al., 2004). This would increase the proportion of fibre in each stem, as opposed to lower plant densities which would produce thicker stems since each would have more room to grow. One idea put forward is that thinner stems may instead contain slightly less fibre than thicker stems, yet have less coarse fibre, and so be easier to ret. This would limit losses in quality (Couture et al., 2002). Conversely, thicker stems might contain more fibre cells, therefore leading to a higher overall fibre concentration (Hocking et. al., 1987).

However, Easson and Molloy (2000) conducted a study under European conditions that indicated little increase in straw and fibre yields with a higher than normal seeding rate. Yet at a lower than normal seeding rate total fibre yield was significantly reduced. They also found that seeding rate had no effect on seed yield in either flax or linseed except for at the lowest seeding rate of 500 seeds/m^2. Another European study, conducted in Italy, investigating different stand densities also found that seed yields were not affected by seeding rate (Casa et al., 1999). Flax plants can compensate for low seeding rates by producing more capsules per plant (Casa et al., 1999, Taylor and Morrice, 1991), which may explain why some lower seeding rates may not have a large effect on seed yield. However, these studies were carried out in separate regions of Europe, which have different environmental conditions than western Canada.

Lafond (1993) found that the seeding rate of oilseed flax had a significant effect on plant density, plant height, and yield when grown in Saskatchewan. As seeding rate was increased, plant density and seed yield increased linearly, while plant height decreased linearly. Couture et al. (2002) conducted a study in Ontario and Quebec, and found that for oilseed and fibre flax cultivars, 'the intense intraspecific competition between plants at high densities is known to stimulate plants to grow tall with little or limited branching'. This is contrary to Lafond's (1993) results. Easson and Molloy (2000) whose study was carried out in Northern Ireland, also found that increased seeding rate decreased plant height, yet they found that effect was more consistent in fibre flax than oilseed flax. According to Easson and Molloy (2000), the standard seeding rate of oilseed flax in Europe is 400 plants/m^2, whereas for fibre flax it is 1800 plants/m^2 as a higher seeding rate is believed to improve the yield and quality of fibre. Taylor and Morrice (1991) also found that as seeding rate was increased, plant height decreased. Higher seeding rates increase the risk of permanent lodging for both oilseed and fibre flax cultivars (Diepenbrock and Pörksen, 1993, Taylor and Morrice, 1991), so that must be taken into consideration when increasing the seeding rate.

Kaul et al. (1994) carried out experiments in Germany using dual-purpose, oilseed, and fibre flax cultivars at a plant density of 2,000 seeds/m^2 and found reduced vegetative growth (with a late seeding date, and warm dry weather conditions). They reduced the seeding rate the second year of their trials to 1,500 seeds/m^2, and changed the harvesting technique to pulling, and better straw fibre yields were achieved.

Gubbels and Kenaschuk (1989) found that as seeding rate increased, seed weight and oil content decreased slightly, iodine number decreased, lodging increased, basal branching decreased, and plant height increased then decreased once a threshold was reached. Seeding rate had a varied influence on seed yield, depending on year and cultivar. Generally, seed yield was maximized at a seeding rate of approximately 30kg/ha.

2.2.4 Row Spacing

Row spacing has been found to have significant effects on plant density of flax at Indian Head, Saskatchewan (Lafond, 1993). Plant density decreased as row spacing increased. Generally, increased row spacing was found to have the same effect as decreasing seeding rate.

Couture et al. (2002) found that as row spacing increased, plant density within rows increased in eastern Canada. As well, plant height was affected, with plant height being greater at the wider row spacings (Couture et al., 2002, Lafond 1993). Higher plant densities were found to increase plant height and limit branching of the plant (Couture et al., 2002). However, higher densities might not always produce taller plants, as climatic conditions, soil structure, and fertility influence plant height (Couture et al., 2002). Diepenbrock et al. (1995) conducted a study at two climatically different regions of Germany, and proposed that widely spaced rows produce strong drought and lodging resistant plants with an increased stem diameter. Narrower row spacings may be used for flax grown on weedier lands to reduce yield loss, whereas with low weed competition, wider row spacings are acceptable (Elsahookie, 1978).

There have been variable results regarding row spacing and seed yield. Row spacings wider than 15cm have decreased seed weight and yield without affecting the number of seeds per boll or bolls per plant (Siemens, 1963), yet other studies showed little effect (Elsahookie, 1978). Elsahookie's (1978) study in Baghdad found that row spacing had no influence on seed and oil yields, or thousand seed weight. However, as row spacing increased, oil percentage decreased while iodine value increased. The difference in iodine levels over row spacings are of low commercial value in the linseed oil industry, so Elsahookie (1978) concluded that any row spacing would be acceptable, and narrower row spacings could still be used on weedy fields with no economic drawback.

2.2.5 Seeding Dates

Preliminary research in Saskatchewan has shown that earlier seeding date leads to higher straw fibre concentration (SAFRR, 2004). This may be attributed to time to bolt, as well as the timing of maturity. Early seeding may be used to achieve earlier maturity (Taylor and Morrice, 1991). Seeding date and its influence on flax performance is linked to weather, with early or later seeded flax having a higher chance of encountering frost or drought. An early spring frost may injure a crop, but the potential loss from a fall frost is far greater. Sheppard and Bates (1988) also found earlier seeding resulted in greatest seed yields and largest response to nitrogen. Later seeding significantly decreased both the mean yields and the response of seed yield to nitrogen.

A study conducted in Germany found that a late sowing date and a high plant density (combined with warm and dry weather conditions) led to reduced vegetative plant growth (Kaul et al, 1994). Taylor and Morrice (1991) also found that plant density was greater at later sowing dates. Dimmock et al. (2005) conducted a study in north Wales, and found that fibre content (but not harvest yield) decreased when seeding was postponed past mid-May.

2.2.6 Nitrogen

Nitrogen is a major plant nutrient that is essential for flax growth and development (Hassan and Leitch, 2000), and is a major input in crop production (Grant et al., 2004). Flax responds well to nitrogen fertilizer if soil nitrogen levels are low (Flax Council of Canada, 2004). There is a limited response to nitrogen applications where soil nitrogen is high (Grant et al., 1999) and yield increases with nitrogen application to flax are often relatively small (Grant et al., 2004). Furthermore, flax response to nitrogen applications fluctuates depending on weather (Sheppard and Bates, 1988), and so responses vary from year to year. There is also a risk of lodging with high rates of nitrogen application (Dimmock et al., 2005). Less than 25 kg/ha of nitrogen is recommended in order to avoid the increased incidence of lodging associated with higher applications. There was no interaction between nitrogen application rate and cultivar in these experiments.

Grant et al. (2004) found that final seed yield increased with increasing nitrogen application rate up to 90 kg N/ha of applied ammonium nitrate, and there was no difference between pre-plant applications or side banding at the time of seeding. Also, oil and protein yield increased with increasing nitrogen application, the result of increased crop yield. Hocking et al. (1987) found a reduction in oil content especially at applied nitrogen levels greater than 50 kg N /ha, and further found that high nitrogen levels may result in reduced oil yields despite increased seed yields. In addition, straw yield showed a linear response to nitrogen fertilizer applications. Ammonium nitrate resulted in higher straw yields than other nitrogen sources. Grant et al. (2004) concludes that nitrogen management will have an impact on both the seed yield and quality as well as straw yield of oilseed flax.

A study done by Rowland (1980) found that nitrogen fertilizer increased straw production in the flax cultivars grown. However, research is beginning to show that lower nitrogen rates could possibly induce higher fibre concentrations in flax straw, even though higher amounts of straw are produced with higher nitrogen levels (SAFRR, 2004). This may be the result of greater amounts of nitrogen leading to lush growth with thicker stems which contain a lower fibre concentration compared to thinner stems with greater fibre concentration grown in low nitrogen conditions.

Nitrogen applications have a variable effect on plant density. In a study by Lafond (1993), plant density was increased by nitrogen in only one year, with no differences in the other years. As well, in the same study, Lafond found that nitrogen effects on plant height were inconsistent.

Nitrogen fertilizer has been found to influence the quality of flaxseed (Grant et al., 2004), by decreasing oil concentration but increasing protein content, as well as increasing oil and protein yield. It is important to monitor flaxseed quality when investigating nitrogen fertilizer effects on straw fibre concentration, as the seed will still be the primary economic product harvested from flax in Canada.

2.3 Near Infrared Reflectance Spectroscopy

A limited amount of research has been conducted on fibre concentration in flax straw because of methodology constraints. Previously, plant tissues had to be 'retted' (a process separating the fibres from the rest of the stem) before the fibre content could be analyzed. This procedure is time-consuming and labor-intensive. However, with the recently developed software technology for Near Infrared Reflectance Spectroscopy (NIR), straw fibre content in flax can now be easily estimated (Barton et al., 2002). NIR analysis facilitates selective breeding for straw fibre concentration since straw fibre can now be measured relatively quickly and in a non-destructive manner.

Any plant sample is made up of different types of molecules, such as water or protein, and the different substances will absorb different wavelengths of light (ASDI, 2006). The NIR instrument measures the number of photons which undergo the absorption process for a particular wavelength. The number of photons absorbed is proportional to the amount of a specific type of molecule present in the sample. This is Beers Law, which states that "absorption is proportional to concentration". A chemometric model is previously compiled by collecting spectra from a group of plant samples scanned by the NIR machine that represent the maximum range of variability for the characteristic being tested. The same group of samples is then tested using a standard analytical method to measure the characteristic of interest, and the independent and spectral data are compared using chemometrics software. A mathematical model is then created that describes the relationship between particular spectral features and the characteristic of interest, called a calibration. Therefore, a new sample can be scanned, and the calibration interprets the information coming from the NIR instrument, and gives a prediction of the characteristic of interest in that plant sample. This technology can be used to test many different characteristics of a variety of crops from straw to seed components.

2.4 CDC Flax Breeding Program

Early in the Flax Breeding Program at the Crop Development Centre, (F_3-F_6), seeding rate is quite variable, and a wider row spacing (30 cm) is used, whereas later in the program (F_6 onwards) seeding rate is constant, and a narrower row spacing is used (15 cm) (G. Rowland, personal communication). Seeding begins in mid-May and finishes in early June. Nitrogen fertilizer applications are not currently part of the Flax Breeding Program at the Crop Development Centre. It is not known what the effects of these variable agronomic practices have on straw fibre concentration in oilseed flax.

3.0 Materials and Methods:

3.1 Characteristics of plant materials

Three experiments were conducted on adjacent fields at the Kernen Crop Research Farm near Saskatoon, SK in order to investigate the effects of various agronomic practices on straw fibre concentration in oilseed flax. In all three experiments, the same four flax cultivars were used; three oilseed and one fibre flax cultivar. These cultivars were chosen based on their expected straw fibre concentration. CDC Mons, Vimy, and CDC Gold were expected to have low, medium and high straw fibre concentrations, respectively, while a consistently high concentration was expected for Hermes, the fibre flax cultivar.

CDC Mons was registered and released by the Crop Development Centre (CDC) in 2002. It is classified as having small seed with good oil content, and is a medium-late maturing cultivar with very good resistance to lodging. Vimy was registered and released in 1986 by the CDC. It has a large seed, medium maturity, high seed oil content and quality but has weak straw. CDC Gold was registered and released in 2003, and is classified as a solin cultivar. Solin cultivars have yellow seed, and have a very different seed oil profile from linseed flax cultivars. Solin cultivars have less than 5% alpha-linolenic acid compared to more than 50% in linseed flax. As a result, solin cultivars have lower iodine values than brown-seeded flax. The fourth cultivar used was the European fibre cultivar Hermes, expected to have the highest straw fibre concentration of the four cultivars. Fibre cultivars are grown for fibre in their straw rather than for their seed, and are normally taller, with less branching and lower seed yield than linseed flax cultivars.

3.2 Site Description and Plot Maintenance

All three experiments were conducted just east of Saskatoon, Saskatchewan at the Kernen Crop Research Farm in 2004 and 2005. This site is located within the Dark Brown soil zone, and has a clay loam soil texture. Plots were seeded with a conventional small plot seeder, and were the standard plot size of 5.2 m^2 used in the CDC Flax Breeding Program. Border plots were seeded at the edges of each experiment. Thousand seed weight measurements of each cultivar were determined before seeding. This was used to accurately calculate seeding rates. For weed control bromoxynil + MCPA

(Buctril M®) and fenoxaprop-p-ethyl (Puma Super®) were sprayed June 21, 2004. In 2005 bromoxynil + MCPA (Buctril M®) was sprayed June 9, and clethodim (Prism®) on June 16. Plots were hand weeded as needed throughout the growing season. The three experiments were desiccated using diquat (Reglone®) in 2004 and 2005 prior to sampling and harvest. All three trials were desiccated on the same day each year; September 8th in 2004, and September 23rd in 2005.

3.2.1 Seeding Rate and Row Spacing

This experiment investigated the relationship between seeding rate and row spacing on straw fibre concentration. Two row spacings were used: 36cm, and 18cm, which are the spacings used in the breeding program. These translated into 4 row and 8 row plots, respectively. Three seeding rates were used which represent the approximate range used in the breeding program: 15, 30 and 45 kg/ha. Seeding rate was adjusted to account for germination percentage differences between the cultivars. This was a three factorial randomized complete block experiment, with seeding rate, row spacing, and cultivars as the factors, with three replicates. This experiment was seeded on May 12th, 2004, and May 16th, 2005. Whole plant samples were taken on September 27th, 2004 for replicates one and two, and September 28th, 2004 for replicate 3. In 2005, samples were taken October 5th, 2005 for replicate 1, and October 6th, 2005 for replicates 2 and 3.

3.2.2 Seeding Date

Seeding dates were investigated, to determine if different dates effect fibre concentration in the straw. In this experiment, three different seeding dates were evaluated: mid May, late May, and early June. These dates reflect the large range of time that different yield and nursery trials are seeded in the CDC Flax Breeding Program, largely depending on weather. This experiment was a split plot, three replicate, randomized complete block design, with seeding date as the main plot and cultivar as the sub-plot. Seeding rate was the standard seeding rate of 30 kg/ha used in the CDC Breeding Program. In 2004, the three seeding dates were May 11th, May 20th, and June 2nd. In 2005 the three seeding dates were May10th, May 26th, and June 6th. Straw samples were taken September 10th, 2004, and September 26th, 2005.

3.2.3 Nitrogen Fertilizer

This was a fertilizer by cultivar trial, to determine if nitrogen fertilizer applications affect straw fibre concentration. This was a two factorial randomized complete block design, with three replicates. Nitrogen fertilizer rate and cultivars were the two factors. Nitrogen was the only fertilizer material evaluated as flax has a variable response to phosphate fertilizer and there is no evidence that phosphorous effects straw fibre concentrations. Seeding rate was the standard seeding rate of 30 kg/ha used in the CDC Flax Breeding Program. Four nitrogen fertilizer rates were used: 0, 20, 40, and 60 kg N/ha of nitrogen as 34-0-0 (ammonium nitrate), and were side-banded one inch to the side and one inch below the seed at the time of seeding. This experiment was seeded on May 28th, 2004, and June 6th, 2005. Samples were taken September 21st, 2004 for replicate 1, and September 22nd, 2004 for replicates 2 and 3. In 2005, samples were taken October 6th. Lodging was not a problem with this experiment in either year.

Soil tests were carried out prior to seeding to determine the existing soil nitrogen level. Soil samples were randomly taken from 0-15 cm and 15-30 cm within the area of the intended experiments. Samples for each depth were then combined, mixed, sub-sampled, and sent to Enviro Test Laboratories, Saskatoon for analysis. Both in 2004 and in 2005, the existing available nitrogen levels in the soil were found to be sufficient. The NO_3-N was found to be 67 kg N/ha in the 0-15 cm depth, and 59 kg N/ha in the 15-30 cm depth in 2004. In 2005, NO_3-N was found to be 67 kg N/ha from 0-15 cm, and 49 kg N/ha in the 15-30 cm depth.

3.2.4 Measurements and Sampling

Plant population density was determined. A meter stick was laid down approximately 1m into the middle of the plot, and individual plants were counted along the meter stick in one row, and then counted on the other side of the stick in the adjacent row. Plant height measurements were taken at the end of the growing season from each plot in each experiment. Three plant height measurements were taken randomly in the plot, and an average height was calculated. The middle rows of the plots were used in both the plant height and plant density measurements so as to avoid any edge effects from the outside rows.

Two areas of whole plant samples were taken from each plot, one from the front, one from the back in order to represent the entire plot. A small area of plants was hand pulled to make up these samples. In 2005 $0.25m^2$ samples were taken in order to estimate fibre yield. These samples were tagged and bagged, and then placed in dryers to make sure that the plants were uniformly dry. The remainder of each plot was harvested using a small plot combine.

Once the whole plant samples were dried, they were weighed, and then chopped using a hand chopper to give 19 cm long straw samples. The straw samples were then weighed to calculate an estimate of harvested fibre yield (kg/ha). The bolls cut from the whole plant samples were saved and then threshed using a Vogel thresher, and the seed collected, which was then added to the seed harvested by the combine from the corresponding plot. The seed was then cleaned, and weighed to estimate total seed weight per plot, as well as thousand seed weight values.

3.3 Near-Infrared Spectroscopy

The straw samples were analyzed for fibre content using the Foss 6500 Near-Infrared Spectrophotometer (NIR). The 19 cm long samples were scanned in a sample cup. Visible/near-infrared spectra were obtained in reflectance mode, with a wavelength range of 400-2498 nm. The sample was sub-scanned 4 times, and the average of the 4 sub-scans was used. In between each sub-scan, the sample was taken out of the sample cup and shuffled by hand, to ensure that the whole sample would be scanned, and a representative straw fibre concentration would be achieved. The software package WINISI was used to operate the NIR machine. The average spectra value was compared to a library of 621 known samples to give an estimated straw fibre value (%).

In both years, random straw samples were taken from the seeding date experiment and sent to a lab to be analyzed (after being analyzed using the NIR). The actual straw fibre concentration values were achieved using wet chemistry analysis. The estimated values given by the NIR were then correlated with the wet chemistry straw fibre concentration values.

Seed samples were also prepared, and tested for protein and oil content to examine their relationship with straw fibre concentration. These values were obtained also using the Foss 6500 NIR.

3.4 Statistical Analysis

All data were subjected to ANOVA using the GLM procedure in SAS (SAS Institute Inc., © 2002-2003) to determine main effects and interactions on the parameters described previously. Levene's test for homogeneity was conducted on fibre, plant height, plant density, thousand seed weight, as well as total seed yield for each experiment. Correlations on data combined from both years for plant height, plant density, fibre yield (kg/ha), thousand seed weight, seed yield (kg/ha), protein, and oil content with regards to fibre concentration were also completed using the SAS program. Regression analyses were performed for seeding rate and row spacing, seeding date, nitrogen concentration and straw fibre concentrations.

4.0 Results:

Weather varied considerably from the 2004 to the 2005 growing seasons. In 2004, there was a cooler than normal trend, including some mid-season frosts. There was adequate precipitation throughout the 2004 growing season, and a lack of heat stress (Table 4.1). There were freezing temperatures in late August, and cool temperatures continued into September. Temperatures during the 2004 growing season were among the coolest reported in the last 100 years (Burnett, 2004). There were quite heavy rains in the beginning of the 2005 growing season. June 2005 is tied with June 1953 for the wettest month in the past 90 years (DeClercq, 2004). There were moderate temperatures throughout the remainder of the growing season.

Levene's test for homogeneity of error variances was conducted on plant and seed characteristics in order to determine if data for both years could be combined. All data that follows is discussed separately for each year since error variances for all characteristics were found to be heterogeneous for all three experiments. Regression analyses were performed for each year in each experiment, and only one year for one experiment resulted in the regression having significance, which was the seeding rate and row spacing experiment for 2005. Correlation analyses were conducted on the random samples taken from the seeding date experiment that were first scanned in the NIR, and then sent to Biolin to achieve straw fibre concentration values using wet chemistry. It was found that there was a high correlation in both years ($R = 0.81$ in 2005), giving credibility to the NIR scanning system and protocol.

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Table 4.1: Climate data for the 2004 and 2005 growing seasons at Saskatoon, Saskatchewan.

	May	**June**	**July**	**August**	**September**	**October**
2004						
Mean temperature (^oC)	8.5	13.1	17.3	14.6	10.7	3.3
Precipitation (mm)	27.0	79.7	75.0	73.5	21.0	28.9
2005						
Mean temperature (^oC)	10.2	14.4	17.5	15.4	11.3	5.2
Precipitation (mm)	27.5	160.5	53.5	53.5	74.0	18.0
30 year average						
Mean temperature (^oC)	11.5	16	18.2	17.3	11.2	4.5
Precipitation (mm)	49.4	61.1	60.1	38.8	30.7	16.7

4.1 Seeding Rate and Row Spacing

4.1.1 Plant Characteristics

Plant density was affected by row spacing ($P < 0.01$), seeding rate ($P < 0.01$) and cultivar in both years ($P < 0.01$) (Table 4.2). The 18 cm row spacing plots (8 rows) had fewer plants than the 36 cm row spacing (4 rows) plots in both years, with an average of 417 plants/m^2 compared to 738 plants/m^2, respectively (Table 4.3). Competition between rows was greater than inter-row competition for germination and seedling survival. The highest seeding rate resulted in the greatest number of plants in 2004 and 2005. Plant density decreased with decreasing seeding rate in both years, from an average of 859 plants/m^2 at 45 kg/ha to 312 plants/m^2 at 15kg/ha. CDC Mons consistently resulted in the highest plant density both years, with an average of 812 plants/m^2 (Table 4.4). Hermes had the lowest plant density both years with an average of 426 plants/m^2. In 2005 CDC Gold, Vimy, and Hermes had similar plant densities of approximately 500 plants/m^2 (Table 4.4). There was a significant interaction between row spacing and cultivar in 2004 ($P < 0.05$) (Fig. 4.1). All cultivars had a lower plant density at the 18 cm row spacing. A significant interaction was present between seeding rate and cultivar in 2004 ($P < 0.05$) (Fig. 4.2). Plant density was increased for all cultivars with increasing seeding rate. Also, there was a significant interaction between row spacing, seeding rate and cultivar in 2005 ($P < 0.01$), and between row spacing and seeding rate in 2004 ($P < 0.01$) and 2005 ($P < 0.05$).

Seeding rate was significant in both 2004 and 2005, respectively ($P < 0.01$, $P < 0.05$) for plant height (Table 4.2). Plant height was not affected by row spacing. Plant height declined with increasing seeding rate in both years with the 45 kg/ha seeding rate

Table 4.2: Mean squares of plant and seed characteristics from the seeding rate and row spacing experiment at Saskatoon, SK in 2004 and 2005.

	Source	DF	Plant density	Plant height	Straw fibre conc	Straw fibre yield	Seed yield	1000 seed wt	Oil	Protein
2004	Error	46	32752	4.3	2.11		31074	0.06	1.58	1.64
	Rep	2	28469	90.9	0.28		54686	0.16	2.24	2.63
	Rowsp	1	2665267**	2.1	20.08*		326378*	0.05	0.62	2.07
	Srate	2	2357373**	156.4*	12.62*		28751	0.14	0.36	0.22
	Cultivar	3	807795**	3034.0**	60.83**		917355**	0.37*	62.20**	92.09**
	Rowsp*srate	2	259644*	30.0	2.35		6853	0.09	0.83	1.91
	Srate*cultivar	6	102833*	7.6	5.78*		17271	0.09	0.70	0.50
	Rowsp*cultivar	3	134519*	39.8	0.54		28311	0.02	0.51	0.91
	Rowsp*srate*cultivar	6	36909	31.3	1.62		34691	0.06	1.89	1.45
2005										
	Error	46	1116972	15.8	0.67	1.50	8441	0.57	0.29	0.27
	Rep	2	14721	30.7	0.53	2.47	25215	0.61*	0.74	1.62*
	Rowsp	1	1195960**	7.7	3.54*	0.26	638318**	0.07	1.45*	2.28*
	Srate	2	1317473**	111.9*	31.87**	50.06**	29187*	0.04	0.05	0.12
	Cultivar	3	308510**	3401.8**	45.79**	108.28**	1068337**	2.91**	98.48**	119.53**
	Rowsp*srate	2	116139*	15.8	0.67	0.01	7907	0.43	0.25	0.44
	Srate*cultivar	6	52278	14.9	1.29	0.42	2055	0.35*	0.15	0.26
	Rowsp*cultivar	3	66560	27.8	1.61	4.93*	75911**	0.17	0.08	0.24
	Rowsp*srate*cultivar	6	84796*	14.3	1.35	1.66	12289	0.11	0.19	0.32

*   significant at P < 0.05
** significant at P < 0.01

Table 4.3: Mean values of various characteristics of four flax cultivars averaged over two row spacings and three seeding rates at Saskatoon, SK in 2004 and 2005.

	Treatment		Plant no. m^{-2}	Height (cm)	Straw fibre (%)	Fibre yield (kg/ha)	Seed yield (kg/ha)	1000 seed wt (g)	Oil (%)	Protein (%)
2004	**Spacing**	36 cm	776a*	60.4a	20.3b	-	1646b	5.7a	42.9a	23.7a
		18 cm	392b	60.7a	19.2a	-	1905a	5.7a	43.1a	23.3a
	Seeding Rate	15 kg/ha	288c	62.9a	19.1b	-	1700a	5.7a	43.1a	23.4a
		30 kg/ha	552b	60.9ab	20.5a	-	1825a	5.7a	43.0a	23.6a
		45 kg/ha	912a	57.8b	19.7ab	-	1801a	5.6a	42.9a	23.6a
	Mean		584	60.6	19.8		1776	5.7	43.0	23.5
2005	**Spacing**	36 cm	699a	56.8a	16.4b	212a	1398b	6.4a	41.8b	25.2a
		18 cm	442b	57.5a	16.0a	210a	1761a	6.4a	42.1a	24.8b
	Seeding Rate	15 kg/ha	336c	59.6a	15.1c	183c	1505b	6.4a	41.9a	25.1a
		30 kg/ha	570b	56.2b	16.1b	210b	1636a	6.4a	42.0a	25.0a
		45 kg/ha	805a	55.7b	17.4a	239a	1598ab	6.4a	41.9a	24.9a
	Mean		570	57.2	16.2	211	1580	6.4	42.0	25.0
	Mean 36 cm		738	58.6	18.4		1522	6.1	42.4	24.5
	Mean 18 cm		417	59.1	17.6		1833	6.1	42.6	24.1
	Mean 15 kg/ha		312	61.3	17.1		1603	6.1	42.5	24.3
	Mean 30 kg/ha		561	58.6	18.3		1731	6.1	42.5	24.3
	Mean 45 kg/ha		859	56.8	18.6		1700	6.0	42.4	24.3

*Means within columns and treatments, followed by a common letter are not significantly different ($P = 0.05$) by the Duncan's Multiple Range Test.

Table 4.4: Mean values of various characteristics of four flax cultivars averaged over two row spacings and three seeding rates at Saskatoon, SK in 2004 and 2005.

	Cultivar	**Plant no. m^{-2}**	**Height (cm)**	**Straw fibre (%)**	**Fibre yield (kg/ha)**	**Seed yield (kg/ha)**	**1000 seed wt (g)**	**Oil (%)**	**Protein (%)**
2004	CDC Gold	517b*	52.3c	19.4b	-	1736b	5.7a	44.0a	25.7a
	CDC Mons	856a	50.5c	17.6c	-	2054a	5.5b	44.3a	21.3b
	Hermes	350c	78.9a	22.1a	-	1177c	5.7a	40.3b	25.2a
	Vimy	614b	60.5b	19.9b	-	2132a	5.7a	43.5a	21.8b
2005	CDC Gold	511b	48.8c	16.0b	177c	1517c	6.4b	43.1a	27.8a
	CDC Mons	767a	47.5c	14.4c	210b	2013a	5.9c	43.2a	22.8c
	Hermes	502b	77.2a	18.2a	277a	948d	6.4b	38.4b	26.6b
	Vimy	502b	55.0b	16.3b	177c	1840b	6.9a	43.0a	22.8c
	Mean CDC Gold	514	50.6	17.7		1627	6.1	43.6	26.8
	Mean CDC Mons	812	49.0	16.0		2034	5.7	43.8	22.1
	Mean Hermes	426	78.1	20.2		1063	6.1	39.4	25.9
	Mean Vimy	558	57.8	18.1		1986	6.3	43.3	22.3

* Means within columns and treatments, followed by a common letter are not significantly different ($P = 0.05$) by the Duncan's Multiple Range Test.

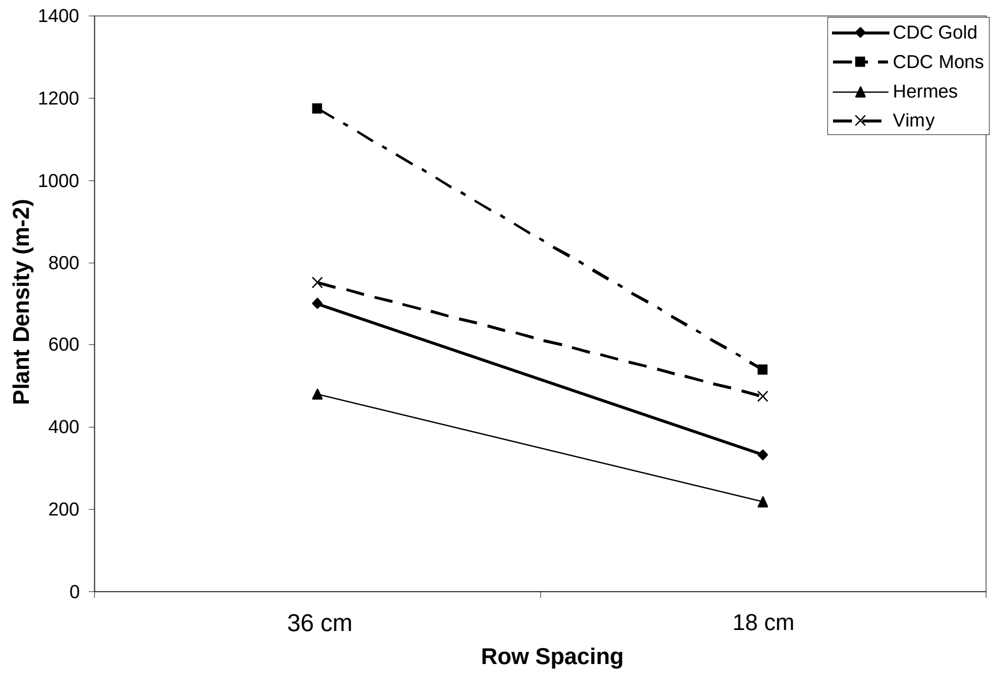

Figure 4.1 Effect of row spacing on plant density of the four flax cultivars at Saskatoon in 2004, $LSD_{0.05}$= 297

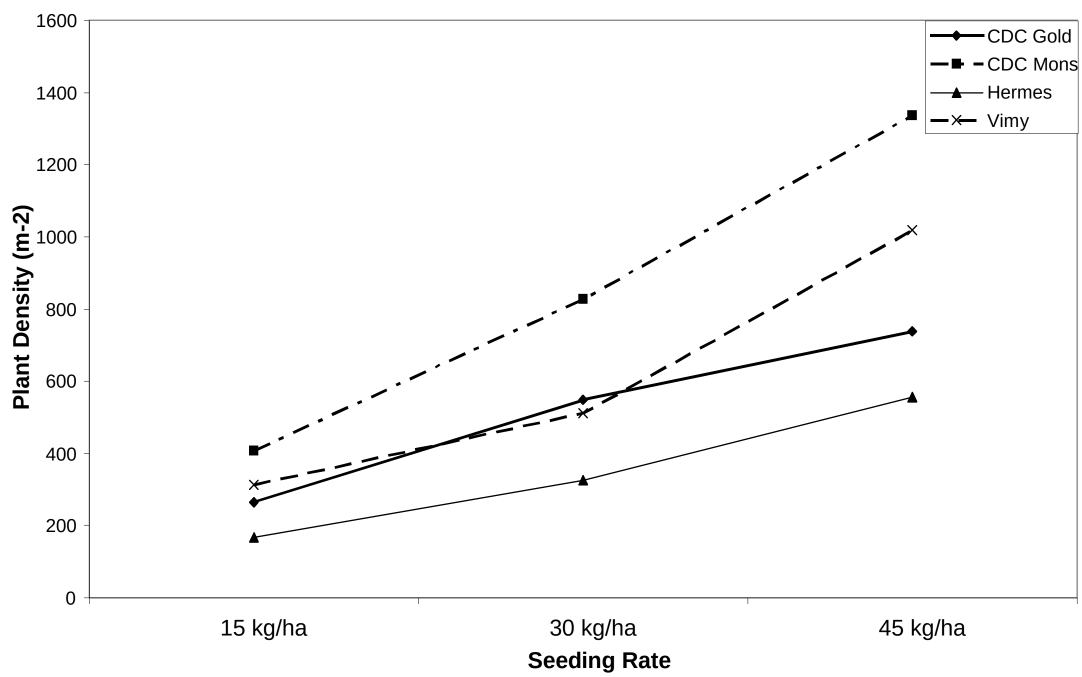

Fig. 4.2 Effect of seeding rate on plant density of the four flax cultivars at Saskatoon in 2004, $LSD_{0.05}$= 297

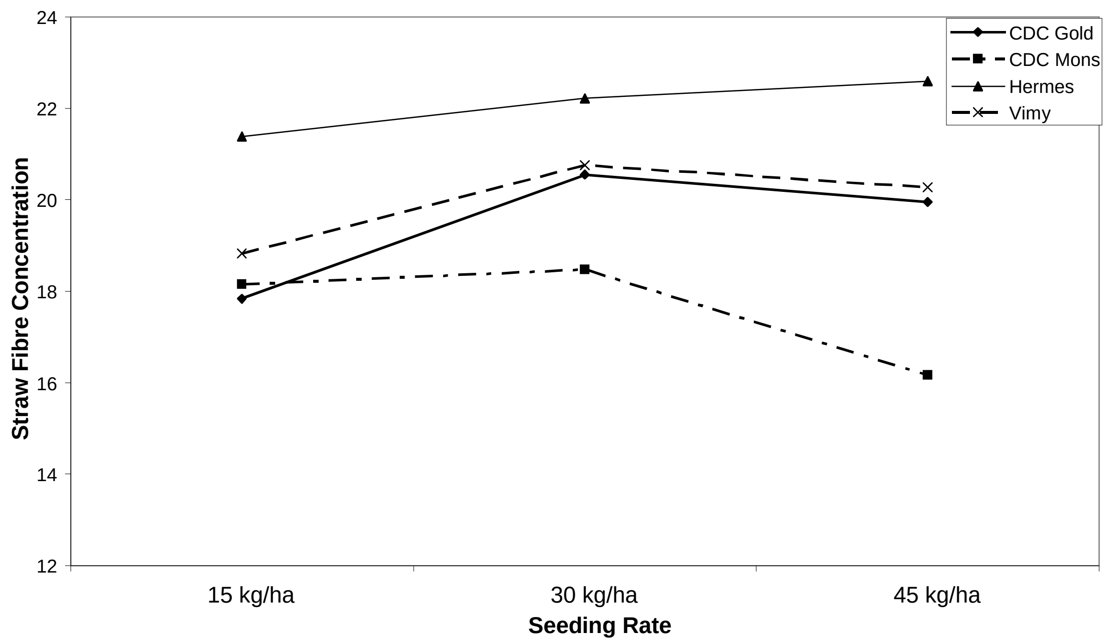

Fig. 4.3 Effect of seeding rate on straw fibre concentration of the four flax cultivars at Saskatoon in 2004, $LSD_{0.05}$= 3.1

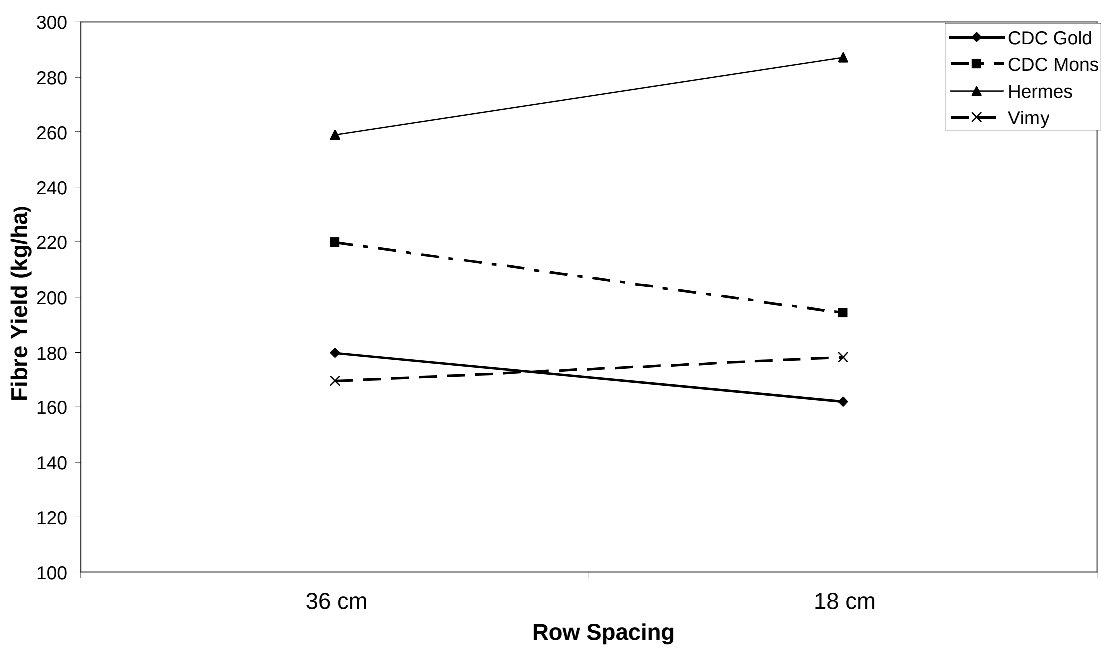

Fig. 4.4 Effect of row spacing on fibre yield of the four flax cultivars at Saskatoon in 2005, $LSD_{0.05}$= 2.0

having significantly shorter plants than the 15 kg/ha seeding rate (Table 4.3). Plants seeded at the 45 kg/ha rate were on average 57 cm tall, compared to 61 cm for plants seeded at 15 kg/ha. Cultivars differed in height ($P < 0.01$) both years (Table 4.2). From tallest to shortest plants, the cultivars were in the same order each year: Hermes > Vimy > CDC Gold which was equal to CDC Mons (Table 4.4). Hermes was significantly taller than the other cultivars, with an average of 78.1 cm compared to 49.0 cm for CDC Mons.

Straw fibre concentration (%) was significantly affected by row spacing ($P < 0.01$, $P < 0.05$), seeding rate ($P < 0.01$) and cultivar ($P < 0.01$) both years (Table 4.2). The 36 cm row spacing resulted in slightly higher fibre concentration than the 18 cm row spacing in both 2004 and 2005, with an average of 18.4% compared to 17.6% (Table 4.3). The difference in fibre concentration as affected by the row spacings decreased in 2005. The 30 and 45 kg/ha seeding rates resulted in higher straw fibre concentrations than the 15 kg/ha rate in both years. Cultivars differed in fibre concentration ($P < 0.01$) both years (Table 4.2). Hermes consistently produced the highest straw fibre concentration, with CDC Gold, Vimy, and CDC Mons following in decreasing order for both 2004 and 2005 (Table 4.4). The fibre levels were lower in 2005 with an average of 16.2% compared with 19.8% in 2004. In 2004 there was a significant interaction between seeding rate and cultivar ($P < 0.05$) (Fig. 4.3), the result of low fibre concentration of CDC Mons at the 45 kg/ha seeding rate.

Seeding rate had a significant ($P < 0.01$) effect on straw fibre yield in 2005, while row spacing was not significant. The highest seeding rate of 45 kg/ha produced the greatest straw fibre yield of 238 kg/ha, which decreased to 183 kg/ha at the 15 kg/ha seeding rate (Table 4.3). Cultivar ($P < 0.01$) was significant for straw fibre yield in 2005 (Table 4.2). Hermes produced the highest straw fibre yield with 277 kg/ha, and CDC Mons the second highest at 210 kg/ha. CDC Gold and Vimy produced the lowest straw fibre yields, both with 177 kg/ha (Table 4.4). There was also a significant interaction between row spacing and cultivar ($P < 0.05$) (Fig. 4.4), caused by the greater straw fibre yield of Hermes at the narrower row spacing.

4.1.2 Seed Characteristics

The effect of row spacing on seed yield was significant in 2004 ($P < 0.05$) and 2005 ($P < 0.01$) as was seeding rate in 2005 ($P < 0.05$) (Table 4.2). Seed yields were higher in both years for the 18 cm row spacing, with an average of 1833 kg/ha compared to 1522 kg/ha for the 36 cm row spacing (Table 4.3). Seeding rate had no effect on seed yield in 2004 whereas in 2005 there was a significantly higher seed yield at 30 kg/ha compared to 15 kg/ha. Cultivar ($P< 0.01$) was significant for seed yield in both years (Table 4.2). As Hermes is a fibre flax cultivar it was not surprising that it produced the lowest seed yield in both years while CDC Mons produced the highest (Table 4.4). There was only one significant interaction for seed yield and that was for row spacing and cultivar in 2005 ($P< 0.01$) (Fig. 4.5), caused by the much lower seed yield of Hermes at both row spacings.

Cultivar was significant ($P < 0.01$) in both years for thousand seed weight (Table 4.2), but thousand seed weight was not affected by row spacing or seeding rate (Table 4.3). Thousand seed weights were greater in 2005, with an average of 6.4g, compared to 5.7g in 2004 (Table 4.3). CDC Mons had the lowest thousand seed weight both years, with an average of 5.7g, whereas Vimy had the highest average thousand seed weight of 6.3g (Table 4.4). There was a seeding rate by cultivar interaction in 2005 ($P< 0.05$) (Fig. 4.6), caused by the thousand seed weight of Hermes increasing as seeding rate increased, whereas in the three oilseed cultivars thousand seed weight decreased with increasing seeding rate.

Row spacing had no effect on oil content in 2004, but was significant in 2005 ($P< 0.05$) (Table 4.2). The 18 cm row spacing resulted in significantly higher oil content in 2005, with 42.1% compared to 41.8% for the 36 cm row spacing (Table 4.3). Seeding rate had no effect on oil content in either year. Cultivar was significant both years ($P< 0.01$) for oil content (Table 4.2). The three oilseed cultivars had similar average oil contents, with CDC Gold at 43.6%, CDC Mons at 43.8%, and Vimy at 43.3%. Hermes had the lowest oil content in both years, with an average of 39.4% (Table 4.4).
Protein was not affected by row spacing in 2004, but was significant in 2005 ($P< 0.01$) (Table 4.2). Protein values were higher in 2005, with an average of 25.0% compared to 23.5% in 2004 (Table 4.3). In 2005 the 36 cm row spacing resulted in slightly higher protein content than the 18 cm row spacing, with 25.2% compared to 24.8% (Table 4.3). Seeding rate had no effect on protein in either year. Cultivar ($P< 0.01$) was significant in both years (Table 4.2). CDC Gold had the highest protein concentration in both years

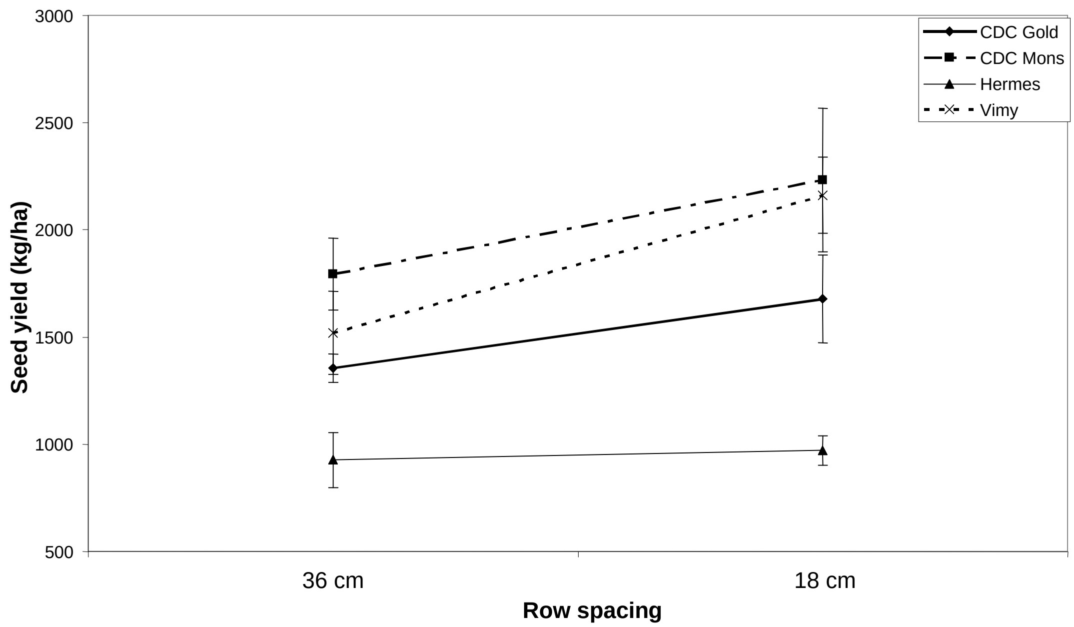

Fig. 4.5 Effect of row spacing on seed yield of the four flax cultivars at Saskatoon in 2005, $LSD_{0.05}$= 150.8

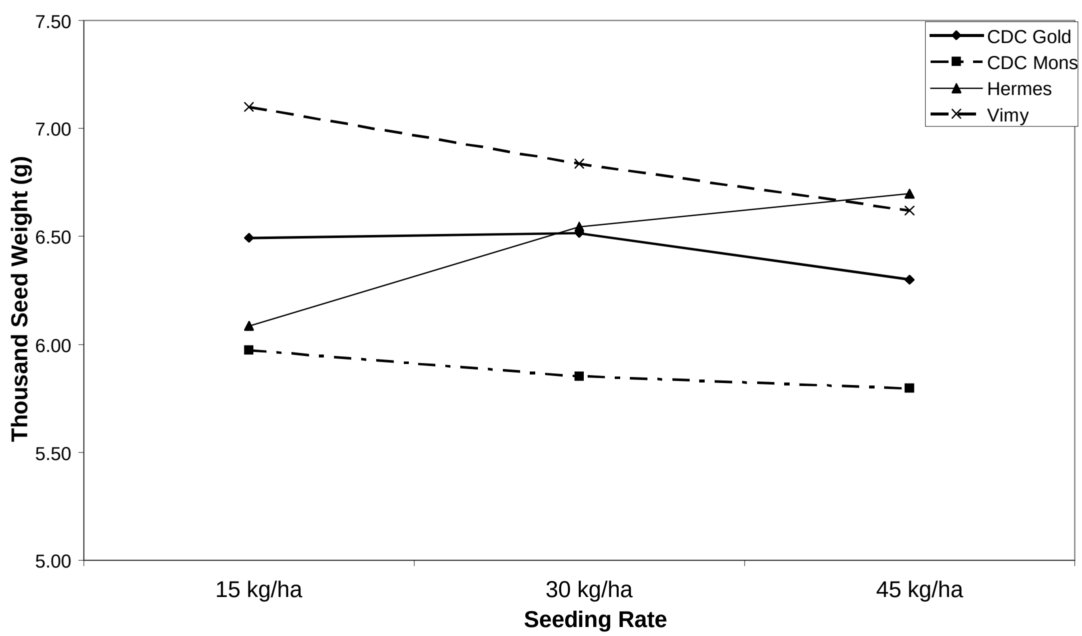

Fig. 4.6 Effect of seeding rate on thousand seed weight of the four flax cultivars at Saskatoon in 2005, $LSD_{0.05}$= 0.63

Table 4.5: Correlations of plant and seed characteristics from the seeding rate and row spacing experiment. Data from all cultivars are shown on the right, and on the left Hermes was excluded from the data set.

All Cultivars (above diagonal); Without Hermes (below diagonal)

	Fibre conc	Straw fibre yield	Height	Plant density	1000 seed wt	Seed yield	Oil	Protein
Fibre conc		0.144	0.522**	-0.145	-0.331**	-0.198*	-0.253**	0.060
Straw fibre yield	0.007		0.433**	0.064	0.255**	-0.441**	-0.674**	0.341**
Height	0.390**	-0.184		-0.367**	0.080	-0.577**	-0.798**	0.305**
Plant density	-0.003	0.253**	-0.314**		-0.153	0.155	0.200*	-0.246**
1000 seed wt	-0.341**	0.107	0.194	-0.250**		-0.184*	-0.239**	0.261**
Seed yield	0.158	0.058	0.350**	-0.049	-0.207*		0.733**	-0.643**
Oil	0.273**	-0.317**	0.017	-0.053	-0.461**	0.184		-0.565**
Protein	-0.111	0.058	0.277**	-0.170	0.258**	-0.516**	-0.361**	

* significant at $P< 0.05$
** significant at $P< 0.01$

followed closely by Hermes, while Vimy and CDC Mons had significantly ($P < 0.01$) lower protein content (Table 4.4).

Correlations were calculated on plant and seed characteristics for the seeding rate and row spacing experiment on data combined from both years. As well, correlations were determined for data from all cultivars, and with Hermes excluded (Table 4.5). Hermes was removed from the correlation calculations as it was the only fibre flax cultivar tested, and could influence the correlation values as fibre flax cultivars have different plant and seed characteristics than oilseed flax cultivars.

Plant height was positively correlated ($P< 0.01$) with straw fibre concentration when Hermes was included in the correlations and when Hermes was removed. Never the less, plant density was not correlated with straw fibre concentration when Hermes was either included or excluded from the data. Thousand seed weight was negatively correlated ($P< 0.01$) with straw fibre concentration with and without Hermes. Seed yield was negatively correlated ($P< 0.05$) with straw fibre concentration for the correlation with all the cultivars included, and was not correlated when Hermes was excluded. Oil content was positively correlated ($P< 0.01$) with straw fibre concentration when Hermes was excluded, and negatively correlated ($P< 0.01$) for all cultivars. Protein and straw fibre yield were not correlated with straw fibre concentration when Hermes was either included or excluded from the correlations.

For straw fibre yield, the only characteristic that was similar when Hermes was both excluded and included in the correlations was oil content. Oil content was negatively correlated ($P< 0.01$) for both sets of correlations. When Hermes was excluded, plant height was not correlated with straw fibre yield, and for all cultivars plant height was positively correlated ($P< 0.01$). Plant density was positively correlated with straw fibre yield ($P< 0.01$) when Hermes was excluded, and not correlated for all cultivars. Thousand seed weight was not correlated with straw fibre yield when Hermes was excluded, and was positively correlated ($P< 0.01$) with all cultivars. Straw fibre yield was not correlated with seed yield when Hermes was excluded, but was negatively correlated ($P< 0.01$) with seed yield for all cultivars. Straw fibre yield was not correlated with protein when Hermes was excluded, and was positively correlated ($P< 0.01$) with protein with all cultivars.

4.2 Seeding Date

4.2.1 Plant Characteristics

The effect of seeding date on plant density was significant ($P< 0.05$) in both 2004 and 2005 (Table 4.6). In both years, mid and early-May seeding resulted in the highest plant densities, with an average of 349 and 343 plants/m^2, respectively (Table 4.7). Early June had a much lower average plant density of 254 plants/m^2. Cultivar ($P< 0.01$) also significantly affected plant density in both years (Table 4.6). CDC Mons produced the highest plant density both years, with an average of 442 plants/m^2 and Hermes produced the lowest plant density, with an average of 204 plants/m^2 (Table 4.8).

Plant height was affected by seeding date in 2004 ($P< 0.05$) (Table 4.6). The early-June seeding date resulted in the tallest plants in both years, with an average of 62.1 cm, while early-May seeding resulted in the shortest plants with an average of 56.4 cm (Table 4.7). In 2005 plants were shorter, with an average of 55.3 cm compared to 62.8 cm in 2004. Cultivar ($P< 0.01$) was significant for plant height in both 2004 and 2005 (Table 4.6). Hermes produced the tallest plants in both years with an average of 78.5 cm, and CDC Mons produced the shortest plants, with an average plant height of 49.7 cm (Table 4.8). The 2005 results also showed influences coming from a seeding date by cultivar interaction ($P< 0.01$) (Fig. 4.7), which was caused by Hermes showing increased plant height at the early-June seeding date while there was little change shown in the three oilseed cultivars.

Straw fibre concentration was affected by seeding date ($P< 0.05$) in both years (Table 4.6). Straw fibre concentrations were higher in 2004, with an average of 17.3% compared with 15.4% in 2005 (Table 4.7). In 2004, plants seeded in mid-May and early-June produced the highest average straw fibre concentrations, of 17.8% and 17.6%, respectively (Table 4.7). Early-May seeding resulted in the lowest straw fibre concentration with 16.6%. In 2005 mid-May seeding produced the highest average straw fibre concentration with 16.1%, while early-May and early-June produced the lowest with 15.2% and 14.8% respectively. Cultivar ($P< 0.01$) was significant both years for straw fibre concentration (Table 4.6). Hermes produced the highest straw fibre concentration in both years with an average of 18.7%, while CDC Mons produced the lowest with an average of 14.6% (Table 4.8). In 2004 there was an interaction between seeding date and

Table 4.6: Mean squares for plant and seed characteristics from the seeding date experiment at Saskatoon, SK in 2004 and 2005.

	Source	**DF**	**Plant density**	**Plant height**	**Straw fibre conc**	**Straw fibre yield**	**Seed yield**	**1000 seed wt**	**Oil**	**Protein**
2004										
	Error	18	4769	7.5	0.38		7622	0.18	0.05	0.09
	Rep	2	11419	1.4	0.40		30842	0.38	0.01	0.03
	Sdate	2	26798*	146.8*	4.84*		76312*	0.36	0.33*	0.11
	Rep*sdate	4	2053	4.9	0.24		6529	0.19	0.01	0.09
	Cultivar	3	64969**	1536.5**	20.82**		499167**	1.74*	56.35**	51.26**
	Sdate*cultivar	6	8895	7.3	1.90*		3833	0.26	0.13	0.28*
2005										
	Error	18	5212	2.4	0.19	1.07	4441	0.14	0.07	0.06
	Rep	2	26427	26.3	0.23	3.36*	6119	0.47	0.48	0.34
	Sdate	2	52826*	66.7	5.76*	4.08*	3338	0.10	1.39*	2.83*
	Rep*sdate	4	4884	13.6*	0.17	0.40	1936	0.20	0.07	0.06
	Cultivar	3	121383**	1644.3**	36.47**	23.68**	458352**	0.53*	60.89**	62.31**
	Sdate*cultivar	6	8312	19.2*	0.29	0.62	8047	0.17	0.06	1.09**

* significant at P < 0.05
** significant at P < 0.001

Table 4.7: Mean values of various characteristics averaged over three seeding dates of four flax cultivars in 2004 and 2005 at Saskatoon, SK.

	Seeding date	Plant no. m^{-2}	Height (cm)	Straw fibre (%)	Fibre yield (kg/ha)	Seed yield (kg/ha)	1000 seed wt (g)	Oil (%)	Protein (%)
2004	May 11 (Early)	331ab*	59.2c	16.6b	-	1692b	6.7a	42.7b	23.7a
	May 20 (Mid)	374a	63.1b	17.8a	-	1997a	6.4a	42.8b	23.5a
	June 2 (Late)	280b	66.2a	17.6a	-	1873a	6.8a	43.0a	23.5a
	Mean	328	62.8	17.3		1854	6.6	42.8	23.6
2005	May 10 (Early)	355a	53.6b	15.2b	187a	1242a	6.8a	41.9a	25.3b
	May 26 (Mid)	323a	54.3ab	16.1a	190a	1303a	6.7a	41.9a	25.2b
	June 6 (Late)	227b	58.0a	14.8b	169b	1255a	6.6a	41.3b	26.1a
	Mean	302	55.3	15.4	182	1267	6.7	41.7	25.5
	Mean Early	343	56.4	15.9		1467	6.8	42.3	24.5
	Mean Mid	349	58.7	17.0		1650	6.6	42.4	24.4
	Mean Late	254	62.1	16.2		1564	6.7	42.2	24.8

* Means within columns and treatments, followed by a common letter are not significantly different (*P* = 0.05) by the Duncan's Multiple Range Test.

Table 4.8: Mean values of various characteristics of four flax cultivars averaged over three seeding dates in 2004 and 2005 at Saskatoon, SK.

	Cultivar	Plant no. m^{-2}	Height (cm)	Straw fibre (%)	Fibre yield (kg/ha)	Seed yield (kg/ha)	1000 seed wt (g)	Oil (%)	Protein (%)
2004	CDC Gold	323b*	54.6c	16.9b	-	1967b	6.4b	44.3a	25.4b
	CDC Mons	449a	53.6c	15.7c	-	2212a	6.2b	44.4a	21.4c
	Hermes	255b	81.7a	19.3a	-	1192c	6.6b	39.1c	25.8a
	Vimy	286b	61.3b	17.2b	-	2043b	7.3a	43.5b	21.6c
2005	CDC Gold	330b	48.4c	15.5b	160c	1264c	6.7ab	42.9ab	28.2a
	CDC Mons	434a	45.8d	13.5d	192b	1653a	6.4b	43.2a	23.3c
	Hermes	153c	75.3a	18.1a	223a	661d	6.7ab	37.8c	27.4b
	Vimy	290b	51.7b	14.3c	156c	1488b	7.0a	42.8b	23.3c
Mean CDC Gold		327	51.5	16.2		1616	6.6	43.6	26.8
Mean CDC Mons		442	49.7	14.6		1933	6.3	43.8	22.4
Mean Hermes		204	78.5	18.7		927	6.7	38.5	26.6
Mean Vimy		288	56.5	15.8		1766	7.2	43.2	22.5

* Means within columns and treatments, followed by a common letter are not significantly different (*P* = 0.05) by the Duncan's Multiple Range Test.

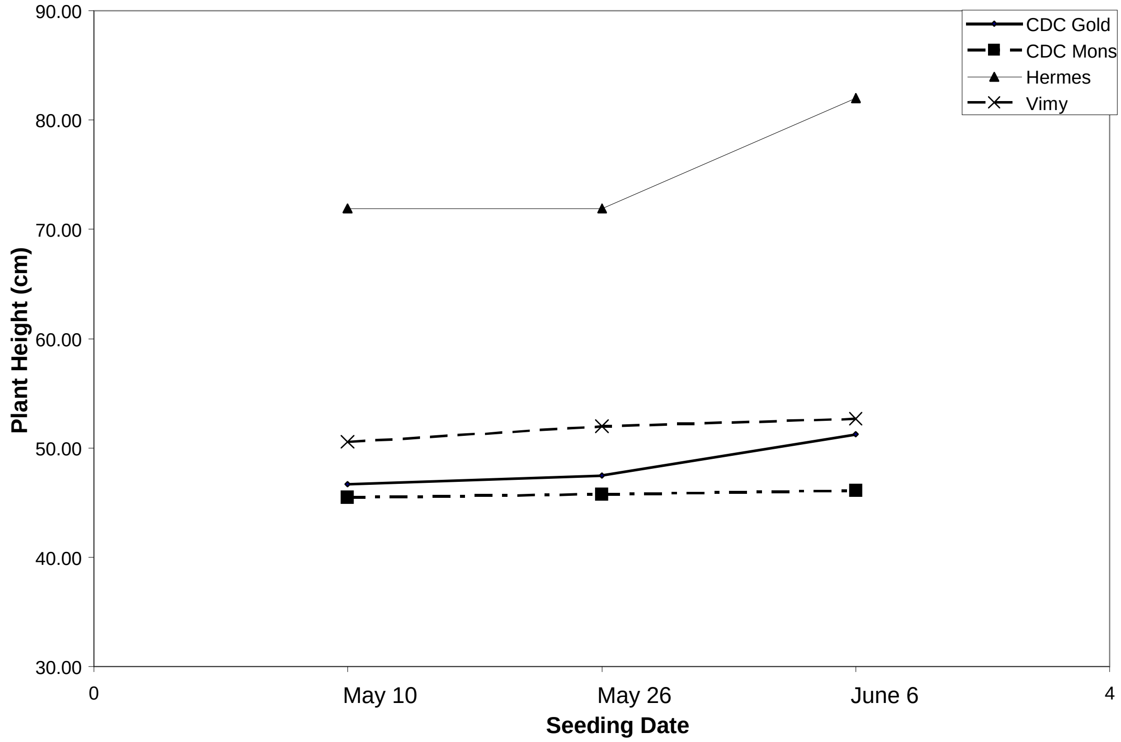

Figure 4.7 Effect of seeding date on plant height of the four flax cultivars at Saskatoon in 2005, $LSD_{0.05}$= 2.7

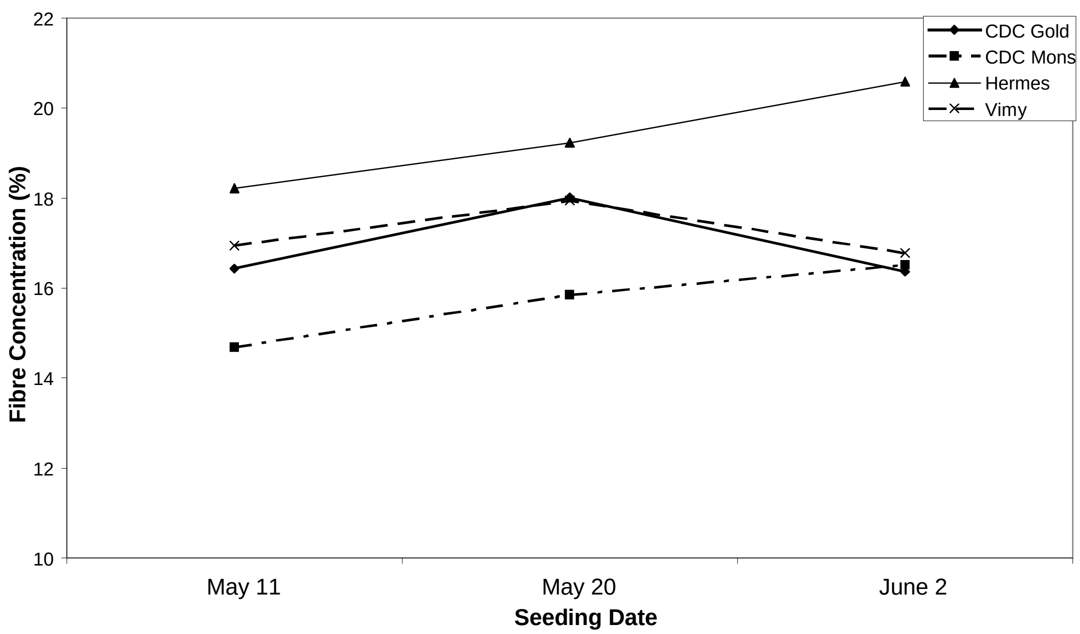

Fig. 4.8 Effect of seeding date on straw fibre concentration of the four flax cultivars at Saskatoon in 2004, $LSD_{0.05}$= 1

cultivar (P< 0.01) (Fig. 4.8), caused by Hermes and CDC Mons having an increased straw fibre concentration at the early-June seeding date, whereas Vimy and CDC Gold had a decreased straw fibre concentration at the early-June seeding date.

Seeding date (P< 0.05) had an effect on straw fibre yield (Table 4.6) in 2005. Early and mid-May had the highest straw fibre yields (186 and 190 kg/ha respectively), while early-June had a lower straw fibre yield (167 kg/ha) (Table 4.7). Cultivar (P< 0.01) was significant for straw fibre yield in 2005 (Table 4.6). Hermes gave the highest yield (223 kg/ha), followed by CDC Mons (192 kg/ha), then CDC Gold and Vimy with similar low straw fibre yields (160 kg/ha and 156 kg/ha respectively) (Table 4.8).

4.2.2 Seed Characteristics

Seeding date had an effect on seed yield in 2004 (P< 0.01), but not in 2005 (Table 4.6). Seed yield was higher in 2004, with an average of 1854 kg/ha compared to 1267 kg/ha in 2005 (Table 4.7). In 2004, mid-May and early-June resulted in higher total seed yields than early-May (1997 kg/ha for mid-May compared to 1692 kg/ha for early-May) (Table 4.7). That trend was also present in 2005, but was not significant. Seed yield differed between cultivars in both years (P<0.01). CDC Mons produced the highest seed yield in both years with an average of 1933 kg/ha, and Hermes produced the lowest seed yield both years, with an average of 927 kg/ha (Table 4.8).

Seeding date had no effect on thousand seed weight (Table 4.6). Thousand seed weight measurements differed between cultivars in both 2004 (P< 0.01) and 2005 (P< 0.05) (Table 4.6). In 2004 Vimy produced the highest thousand seed weight (7.3g), with the other three cultivars being similar (Table 4.8). In 2005 the results were comparable, with Vimy producing the highest thousand seed weight (7.0g). CDC Mons had the lowest thousand seed weight both years.

Oil values were affected by seeding date (P< 0.05) in both years (Table 4.6). Oil values were higher in 2004, with an average of 42.8% compared with 41.7% in 2005 (Table 4.7). In 2004 early-June seeding resulted in the highest oil values (43.0%), whereas in 2005 it gave the lowest (41.3%) (Table 4.7). Early and mid-May seeding resulted in similar oil content in both years. Averaged over both years, early-May had an oil value of 42.3%, mid-May with 42.4%, and early-June with 42.4%, showing that all three seeding dates gave similar oil values. Oil content differed between cultivars both years (P<0.01) (Table 4.6). CDC Mons produced the highest oil value in both years, with an average of 43.8% (Table 4.8). Hermes produced the lowest oil value both years, with an average of 38.5%.

Protein values were not affected by seeding date in 2004, but were in 2005 (P< 0.05) (Table 4.6). Protein values were higher in 2005, with an average of 25.5% compared to 23.6% in 2004. The three seeding dates resulted in similar protein values, with early-May seeding producing an average of 24.5%, mid-May an average of 24.4%, and early-June an average of 24.8%. Cultivar was significant in both years (P<0.01) (Table 4.6). CDC Gold had the highest average protein value of 26.8%, followed by Hermes with 26.6%, Vimy with 22.5%, and CDC Mons having the lowest protein value of 22.4% (Table 4.8). CDC Gold and Hermes were similar with higher protein values, while Vimy and CDC Mons were similar with lower protein values. A seeding date by cultivar interaction was present in 2005 (P< 0.01) (Table 4.6).

Correlations were calculated on plant and seed characteristics for the seeding date experiment on data combined from both years. As well, correlations were conducted on data from all cultivars, and with the fibre cultivar Hermes excluded from the data set (Table 4.9).

Straw fibre concentration was positively correlated with plant height (P< 0.01) both when Hermes was excluded from the data, as well as included. Straw fibre concentration was not correlated with plant density when Hermes was excluded, and was negatively correlated (P< 0.01) when Hermes was included in the data. Seed yield was positively correlated (P< 0.01) with straw fibre concentration when Hermes was excluded, and negatively correlated (P< 0.05) when Hermes was included. Straw fibre concentration was positively correlated (P< 0.01) with oil content without Hermes, and negatively correlated (P< 0.01) when Hermes was included. Protein was not correlated with straw fibre concentration without Hermes, and was positively correlated (P< 0.05)

Table 4.9: Correlations of plant and seed characteristics from the seeding date experiment. Data from all cultivars are shown on the right, and on the left Hermes was excluded from the data set.

Without Hermes (below diagonal) | All Cultivars (above diagonal)

	Fibre conc	Straw fibre yield	Height	Plant Density	Thousand Seed wt	Seed Yield	Oil	Protein
Fibre conc		0.421**	0.822**	-0.409**	0.047	-0.253*	-0.553**	0.279*
Straw fibre yield	-0.091		0.512**	-0.316**	0.107	-0.671**	-0.714**	0.367**
Height	0.636**	-0.286*		-0.560**	0.012	-0.450**	-0.798**	0.280*
Plant density	-0.125	0.088	-0.377**		-0.217	0.544**	0.574**	-0.428**
1000 seed wt	0.140	0.147	0.251	-0.353**		-0.155	-0.037	-0.061
Seed yield	0.443**	-0.307*	0.563**	0.261	-0.271		0.841**	-0.738**
Oil	0.453**	-0.302*	0.299*	0.254	-0.380**	0.736**		-0.567**
Protein	-0.054	0.027	-0.378**	-0.213	-0.051	-0.642**	-0.354**	

* significant at P< 0.05
** significant at P< 0.01

when Hermes was included. Straw fibre concentration was not correlated with straw fibre yield when Hermes was excluded, and positively correlated ($P < 0.01$) with Hermes. Thousand seed weight was not correlated with straw fibre concentration with or without Hermes.

Straw fibre yield was negatively correlated ($P < 0.05$) with plant height when Hermes was excluded, and positively correlated ($P < 0.01$) with Hermes. Straw fibreconcentration was not correlated with plant density without Hermes, and negatively correlated ($P < 0.01$) when Hermes was included. Seed yield and oil content were both negatively correlated with straw fibre yield both when Hermes was excluded ($P < 0.05$) and included ($P < 0.01$). Straw fibre yield was not correlated with protein content when Hermes was excluded, and positively correlated ($P < 0.01$) when Hermes was included. Thousand seed weight was not correlated with straw fibre yield either with or without Hermes.

4.3 Nitrogen Fertilizer

Nitrogen fertilizer rate had no effect on any measured plant or seed variable in either year (Table 4.10).

4.3.1 Plant Characteristics

Plant density was affected by cultivar both years ($P < 0.01$) (Table 4.10). Plant density was higher in 2005, with an average of 338 plants/m^2 compared to 306 plants/m^2 in 2004 (Table 4.11). CDC Mons produced the highest plant densities both years, with an average of 458 plants/m^2 (Table 4.12). Hermes produced the lowest plant density both years, with an average of 236 plants/m^2.

Plant height differed between cultivars both years in the nitrogen fertilizer experiment ($P < 0.01$). Plants of all cultivars were taller in 2004, with an average height of 70.7 cm compared to 57.8 cm in 2005 (Table 4.11). Hermes, not surprisingly, was tallest in both years, with an average of 82.9 cm (Table 4.12). CDC Mons was the shortest in both years, with an average height of 54.8 cm.

Straw fibre concentration was affected only by cultivar in both 2004 and 2005 ($P < 0.01$) (Table 4.10). In 2004 Hermes produced the highest straw fibre concentration (23.7%), followed by CDC Gold (21.6%), Vimy (20.2%), and CDC Mons (19.1%) (Table 4.12). In 2005, the same trend occurred, but only CDC Mons produced significantly (P<

Table 4.10: Mean squares for plant and seed characteristics from the nitrogen fertilizer experiment at Saskatoon, SK in 2004 and 2005.

	Source	DF	Plant density	Plant height	Straw fibre conc	Straw fibre yield	Seed yield	1000 seed wt	Oil	Protein
2004										
	Error	30	4468	5.4	1.16		4823	0.08	0.09	0.47
	Rep	2	6270	30.6*	0.28		5745	0.02	0.15	1.00
	Cultivar	3	133207**	2011.6**	46.16**		1093708**	1.16**	88.09**	84.42**
	Nrate	3	4913	5.4	1.04		5052	0.06	0.10	0.76
	Cultivar*nrate	9	1465	1.7	1.14		9653	0.04	0.17	0.59
2005										
	Error	30	3920	5.2	0.82	0.86	5508	0.12	0.09	0.08
	Rep	2	1820	1.2	0.27	2.33	111781**	0.24	0.12	0.11
	Cultivar	3	97325**	1839.6**	43.49**	30.98**	921585**	1.85**	73.56**	55.41**
	Nrate	3	2669	9.5	0.88	0.49	9322	0.08	0.10	0.03
	Cultivar*nrate	9	6750	3.4	0.33	0.53	1617	0.09	0.03	0.12

* significant at $P < 0.05$
** significant at $P < 0.01$

Table 4.11: Mean values of various characteristics of four flax cultivars averaged over four levels of nitrogen fertilizer applications in 2004 and 2005 at Saskatoon, SK.

	Nitrogen rate	Plant no. m^{-2}	Height (cm)	Straw fibre (%)	Fibre yield (kg/ha)	Seed yield (kg/ha)	1000 seed wt (g)	Oil (%)	Protein (%)
2004	0 kg/ha	306a*	69.8a	20.8a	-	2124a	5.9a	43.3a	23.1a
	20 kg/ha	337a	69.3a	21.1a	-	2176a	6.0a	43.6a	22.8a
	40 kg/ha	302a	72.8a	21.3a	-	2119a	5.8a	42.9a	23.5a
	60 kg/ha	279a	70.7a	21.4a	-	2156a	5.9a	43.1a	23.6a
	Mean	306	70.7	21.2		2144	5.9	43.2	23.3
2005	0 kg/ha	325a	58.2a	16.1a	190a	1839a	6.5a	41.4a	26.1a
	20 kg/ha	359a	56.5a	15.8a	196a	1969a	6.7a	41.3a	26.0a
	40 kg/ha	334a	58.1a	16.1a	198a	1896a	6.5a	41.4a	26.0a
	60 kg/ha	333a	58.4a	16.5a	190a	1894a	6.7a	42.2a	26.1a
	Mean	338	57.8	16.1	194	1900	6.6	41.6	26.1
	Mean 0 kg/ha	316	64.0	18.5		1982	6.2	42.4	24.6
	Mean 20 kg/ha	348	62.9	18.5		2073	6.4	42.5	24.4
	Mean 40 kg/ha	318	65.5	18.7		2008	6.2	42.2	24.8
	Mean 60 kg/ha	306	64.6	19.0		2025	6.3	42.7	24.9

* Means within columns and treatments, followed by a common letter are not significantly different (*P* = 0.05) by the Duncan's Multiple Range Test.

Table 4.12: Mean values of various characteristics of four flax cultivars averaged over four levels of nitrogen fertilizer applications in 2004 and 2005 at Saskatoon, SK.

	Cultivar	Plant no. m^{-2}	Height (cm)	Straw fibre (%)	Fibre yield (kg/ha)	Seed yield (kg/ha)	1000 seed wt (g)	Oil (%)	Protein (%)
2004	CDC Gold	296b*	65.5b	21.6b	-	2426ab	5.8b	44.8a	24.5b
	CDC Mons	444a	61.2c	19.1d	-	2499a	5.5c	44.9a	21.0c
	Hermes	188c	89.8a	23.7a	-	1275c	6.1a	39.2c	26.4a
	Vimy	292b	66.4b	20.2c	-	2370b	6.2a	44.0b	21.2c
2005	CDC Gold	312b	52.6b	16.9a	181bc	1891c	6.7b	42.7a	28.5a
	CDC Mons	471a	48.3c	13.3b	167c	2434a	6.2c	42.9a	24.3c
	Hermes	283b	76.0a	17.5a	239a	1174d	6.4c	37.7c	27.3b
	Vimy	285b	54.3b	16.8a	187b	2098b	7.1a	42.1b	24.2c
Mean CDC Gold		304	59.1	19.3		2159	6.3	43.8	26.5
Mean CDC Mons		458	54.8	16.2		2467	5.9	43.9	22.7
Mean Hermes		236	82.9	20.6		1225	6.3	38.5	26.9
Mean Vimy		289	60.4	18.5		2203	6.7	43.1	22.7

* Means within columns and treatments, followed by a common letter are not significantly different (P = 0.05) by the Duncan's Multiple Range Test.

0.01) lower straw fibre concentration. Hermes produced the highest average straw fibre concentration of 20.6%, while CDC Mons produced the lowest average fibre concentration of 16.2%. Straw fibre concentrations were higher in 2004, with an average of 21.2% compared to 16.1% in 2005 (Table 4.11).

Straw fibre yield differed between cultivars in 2005 ($P < 0.01$) (Table 4.10). Hermes produced the highest straw fibre yield (239 kg/ha), followed by Vimy (187 kg/ha), CDC Gold (181 kg/ha), and CDC Mons (167 kg/ha) (Table 4.12).

4.3.2 Seed Characteristics

Seed yield varied between cultivars both years ($P<0.01$) in the nitrogen fertilizer experiment (Table 4.10). Seed yields were higher in 2004, with an average of 2144 kg/ha compared to 1900 kg/ha in 2005 (Table 4.11). CDC Mons had significantly the highest seed yield both years, with an average of 2467 kg/ha. Hermes, not surprisingly, had the lowest seed yield in both years, with an average of 1225 kg/ha.

Thousand seed weight differed amongst cultivars in both years ($P < 0.01$) (Table 4.10). Thousand seed weights were higher in 2005 with an average of 6.6 g compared with 5.9 g in 2004 (Table 4.11). Vimy had the highest thousand seed weight both years, (6.7 g) (Table 4.12). CDC Mons had the lowest thousand seed weight both years, and had an average of 5.9 g.

Oil content varied between cultivars in both years ($P < 0.01$) of this experiment (Table 4.10). Oil content was higher in 2004 with an average of 43.2% compared to 41.6% in 2005 (Table 4.11). CDC Mons and CDC Gold produced significantly the highest oil content both years, with an average of 43.9% and 43.8%, respectively (Table 4.12). Hermes had the lowest oil content both years, with an average of 38.5%.

Protein content differed between cultivars in 2004 and 2005 ($P < 0.01$) (Table 4.10). Protein contents were higher in 2005 with an average of 26.1% compared with 23.3% in 2004 (Table 4.11). Hermes produced the highest average protein content of 26.9%, followed closely by CDC Gold with an average of 26.5% (Table 4.12). CDC Mons and Vimy produced the lowest protein content (22.7%).

Correlations were calculated on plant and seed characteristics for the nitrogen fertilizer experiment on data combined from both years. As well, correlations were conducted on data from all cultivars, as well as with eliminating Hermes (Table 4.13).

Table 4.13: Correlations of plant and seed characteristics from the nitrogen fertilizer experiment. Data from all cultivars are shown on the right, and on the left Hermes was excluded from the data set.

Without Hermes (below diagonal) / All Cultivars (above diagonal)

	Fibre conc	Straw fibre yield	Height	Plant density	1000 seed wt	Seed yield	Oil	Protein
Fibre conc		-0.340**	0.763**	-0.534**	-0.362**	-0.215*	-0.043	-0.069
Straw fibre yield	-0.503**		0.052	-0.142	0.515**	-0.595**	-0.727**	0.662**
Height	0.888**	-0.655**		-0.578**	-0.265**	-0.650**	-0.582**	0.177
Plant density	-0.387**	-0.060	-0.322**		-0.220*	0.518**	0.431**	-0.359**
1000 seed wt	-0.378**	0.673**	-0.475**	-0.340**		-0.222*	-0.311**	0.390**
Seed yield	0.206	-0.455**	0.323**	0.287*	-0.534**		0.901**	-0.668**
Oil	0.668**	-0.778**	0.696**	0.130	-0.823**	0.538**		-0.647**
Protein	-0.300*	0.622**	-0.509**	-0.204	0.466**	-0.576**	-0.553**	

* significant at $P< 0.05$
** significant at $P< 0.01$

Straw fibre concentration was positively correlated ($P< 0.01$) with plant height both when Hermes was included and excluded from the data. As well, straw fibre concentration was negatively correlated ($P< 0.01$) with plant density, thousand seed weight, and straw fibre yield with and without Hermes. Straw fibre concentration was not correlated with seed yield when Hermes was excluded, and was negatively correlated ($P< 0.05$) when Hermes was included. Oil content was positively correlated ($P< 0.01$) with straw fibre concentration without Hermes, and was not correlated when Hermes was included in the data set. Straw fibre concentration was negatively correlated ($P< 0.05$) with protein content without Hermes, and was not correlated when Hermes was included.

For straw fibre yield, only plant height had a different result from the correlations when Hermes was included or excluded from the data. Every other characteristic had the same result with and without Hermes included in the data set. Straw fibre yield was negatively correlated ($P< 0.01$) with plant height without Hermes, and was not correlated when Hermes was included in the data. Thousand seed weight and protein content were positively correlated ($P< 0.01$) with straw fibre yield. Seed yield and oil content were negatively correlated ($P< 0.01$) with straw fibre yield. Straw fibre yield was not correlated with plant density.

5.0 Discussion:

The years 2004 and 2005 were good flax growing seasons but judging from the data gathered from the three experiments, 2004 was the better growing season. This occurred despite the mean temperature being lower every month of the growing season in 2004 compared to the 30 year average (Table 4.1). Even though temperatures were higher in 2005 than in 2004 and there was no mid season frost, record amounts of rain fell during the 2005 growing season, and so the plants were most likely under some excess water stress. Casa et al. (1999) noted that high temperatures during the ripening stage reduced the number of seeds per capsule as well as seed weight, and decreased the oil yield and quality. The lower temperatures throughout the 2004 growing season may be the reason that 2004 was the better growing season. Warmer temperatures later in the growing season allow for good drying weather during flowering and ripening that Sheppard and Bates (1988) believe are beneficial for optimal flax growth. Temperatures were warmer later in the 2005 growing season, which was warmer than 2004, but there was likely too much water present from the early season heavy rains that accumulated on the surface of the high clay content soils at Kernen. Saturation of the soil reduces oxygen supply to roots and microorganisms. In addition September 2005 was also a wet month, so those warmer temperatures likely did not aid in drying and ripening.

The 2004 growing season accentuated the differences amongst cultivars for most traits, such as plant density and seed yield. Also, straw fibre concentration, plant height, seed yield, and oil content were all higher in 2004. Only thousand seed weight and protein content were higher in 2005 than in 2004. The differences in plant and seed characteristics between the two years of this study agree with findings of Sankari (2000), who found that precipitation and temperature differences over a two year study caused a wide variation between oilseed flax cultivars for mean plant density, plant height, stem yield, and seed yield.

Nitrogen fertilizer applications did not have a significant effect on any plant or seed characteristic measured in this experiment (Table 4.10). Flax response to nitrogen applications fluctuates depending on weather (Sheppard and Bates, 1988), and so responses vary year to year. There is always a risk of lodging when nitrogen is applied to flax (Dimmock et al., 2005), but lodging was minimal to non-existent over the two growing seasons in this study, despite abundant nitrogen and moisture. In both 2004 and 2005 existing soil nitrogen levels were tested in the spring, and found to be sufficient. Grant et al. (1999) found that there was a limited response to nitrogen applications where soil nitrogen was high, and yield increases with nitrogen application to flax were often relatively small (Grant et al., 2004). Therefore, plants in this study may have had a greater response to applied nitrogen if the existing soil nitrogen levels had been lower.

When examining the agronomic conditions investigated in these three experiments, the 36 cm row spacing (4 rows) resulted in slightly higher straw fibre concentration than the 18 cm row spacing (8 rows) in both years (Table 4.3). It was found that the competition occurring between the rows was greater than the inter-row competition for germination and seedling survival. This does not greatly effect the CDC Flax Breeding Program as both the 36 cm and 18 cm row spacings are used at different stages during the breeding program. As well, there was only a slight increase in straw fibre concentration with the 36 cm row spacing, and it would not be worth while to re-structure the breeding program.

The 30 and 45 kg/ha seeding rates resulted in higher straw fibre concentrations than the lowest seeding rate of 15 kg/ha (Table 4.3). There was a seeding rate and cultivar interaction present, but only in 2004. In the CDC Flax Breeding Program, (for the F_3-F_6 generations) the seed of a single plant is the source for each row, so the seeding rate is quite variable. In the early stages of the breeding program it would be difficult to maintain a higher seeding rate, whereas after the F_6 generation, the seeding rate in the breeding program is 30 kg/ha, and the results from this study show that this would aid in achieving a higher straw fibre concentration.

Seeding in mid-May resulted in the highest straw fibre concentration in both years (Table 4.7). Dimmock et al. (2005) found that seeding dates past mid-May decreased straw fibre concentration but this finding was not necessarily corroborated by this research, as in 2004 there was only a slight decrease in straw fibre concentration from delaying seeding from mid-May to early-June, but in 2005 there was a significant decrease in straw fibre concentration for plants seeded in early-June. Preliminary research reported by SAFRR (2004) showed earlier seeding dates resulted in higher straw fibre concentrations, which also was not necessarily shown in this research as the early-

May seeding date in 2004 produced the lowest straw fibre concentration. There was a seeding date and cultivar interaction for straw fibre concentration in this study, but it was significant only in 2004.

Nitrogen fertilizer applications had no effect on straw fibre concentration (Table 4.10). Straw fibre concentrations were higher in 2004 for all three experiments, which was most likely due to the differences in weather conditions between growing seasons. The fact that applied nitrogen had no effect on straw fibre concentration is beneficial, since currently the CDC Flax Breeding Program does not apply nitrogen at any stage, and no changes are recommended in that regard, which also saves on costs.

With regards to straw fibre concentration, it is important to note that the cultivars were in the same order from greatest to least in both years of every experiment (Tables 4.4, 4.8, and 4.12). Hermes consistently produced the highest straw fibre concentration, which was to be expected, as Hermes is a fibre flax cultivar and should naturally have higher fibre than oilseed flax cultivars. Vimy and CDC Gold were in the middle in all three experiments. CDC Mons consistently produced the lowest straw fibre concentration. Since these results are so consistent, they lend a great deal of credibility to the NIR system, and the protocol used to determine fibre concentration.

Straw fibre concentration and straw fibre yield were not correlated in the seeding rate and row spacing experiment either when Hermes was included or excluded from the data (Table 4.5). In the seeding date experiment, straw fibre yield was not correlated with straw fibre concentration when Hermes was excluded, and positively correlated with straw fibre concentration when Hermes was included (Table 4.9). In the nitrogen fertilizer experiment, straw fibre yield was negatively correlated with straw fibre concentration both when Hermes was included and excluded from the data (Table 4.13). These results are interesting, since straw fibre yield would be expected to have a strong relationship with straw fibre concentration, as straw fibre yield is partly based on the concentration of fibre in the straw.

These results are not conclusive, as for the three experiments there are three different relationships between straw fibre concentration and straw fibre yield. As straw fibre concentration increases, straw fibre yield should increase, as well as visa versa. The fact that a negative relationship was seen in the nitrogen fertilizer experiment reinforces the idea that more research needs to be conducted in order to properly understand this relationship. Research reported by SAFRR (2004) suggested that higher straw fibre yield would have lower straw fibre concentration because of thicker stems, which would have a lower straw fibre concentration. Easson and Cooper (2002) found that at reduced seeding rates (which would reduce straw fibre yield) there was lower straw fibre concentration, since lower plant densities produce thicker individual stems, meaning a lower straw fibre concentration. More research needs to be done in order to conclusively define the relationship between straw fibre concentration and straw fibre yield.

Straw fibre yield was consistent across the three experiments. Hermes consistently produced the highest straw fibre yield, CDC Mons was in the middle, and CDC Gold and Vimy produced the lowest straw fibre yield in all three experiments (Tables 4.4, 4.8, and 4.12). Hermes understandably produced the highest straw fibre yield since it is a fibre flax cultivar, and also has the highest straw fibre concentration. Therefore it could have a lower plant density, but because it is taller and has a higher straw fibre concentration, both traits of fibre flax cultivars, it still produced the highest straw fibre yield compared to a shorter oilseed cultivar with lower straw fibre concentration. CDC Mons produced the second highest straw fibre yield, which is interesting, because it was consistently the shortest of the four flax cultivars tested, and consistently had the lowest straw fibre concentration. CDC Mons seemed to make up for this by producing the highest plant density, which therefore helps to produce a high straw fibre yield. The higher plant density exhibited by CDC Mons could be attributed to the fact that it has a smaller seed size than the other three cultivars used in these experiments, and so more seeds would be sown at the same seeding rate than the other cultivars. CDC Gold and Vimy produced the same straw fibre yield, since they both had the same straw fibre concentration, and were relatively close to each other in plant height (Vimy was taller in both years).

Row spacing had no effect on straw fibre yield, while straw fibre yield increased with increasing seeding rate (Table 4.3). The highest seeding rate of 45 kg/ha resulted in the highest straw fibre yield, which makes sense since as it results in the highest plant density. As seeding rate decreased, straw fibre yield decreased. These findings correspond with Rowland's (1980) results, as well as Foulk et al. (2004), and Easson and

Cooper (2002), who all found that higher seeding rates increased straw yield. Sankari (2000) also found that dense seeding rates resulted in high stem yield relative to seed yield.

Early to mid-May seeding resulted in the highest straw fibre yields (Table 4.6). Early or late seeded flax is at a higher risk of incurring frost or drought injury. An early frost might injure a crop, but the potential loss from a frost in the fall is far greater as the farmer cannot reseed. It is beneficial to seed flax early in order to maximize straw fibre yield as well as avoid potential losses near harvest.

Nitrogen fertilizer applications had no effect on straw fibre yield (Table 4.11). Hocking et al. (1987) as well as Rowland (1980) found that straw yield increased with increasing nitrogen fertilizer applications. Higher nitrogen fertilizer applications did not increase straw fibre yield in this experiment. SAFRR (2004) has suggested that higher nitrogen applications could possibly lower straw fibre yield, as higher nitrogen leads to higher amounts of straw produced, in the form of thicker stems, which may contain lower fibre concentration. Lower nitrogen fertilizer applications could actually increase straw fibre yield, as the thinner stems produced in low nitrogen conditions may contain greater fibre concentration. Straw fibre yield was not significantly affected by nitrogen applications in this study. The highest straw fibre yield was at 40 kg N /ha of applied nitrogen, and the lowest was at 0 and 60 kg/ha of applied nitrogen. This study, conducted under conditions of ample soil nitrogen supply, does not support research stating that lower nitrogen fertilizer applications increase straw fibre yield.

Plant density was increased in the seeding rate and row spacing experiment by increasing row spacing (at a fixed seeding rate) as well as increasing seeding rate (at a fixed row spacing) (Table 4.3). The highest seeding rate of 45 kg/ha produced the greatest plant density, and as seeding rate decreased, plant density decreased. This research has shown that as plant density increased, straw fibre concentration, and straw fibre yield increased. The increased straw fibre concentration results agree with Booth et al. (2004), as they reported that increasing plant density resulted in thinner plant stems, meaning there would be an increased proportion of fibre in each stem. Couture et al. (2002) suggested that thinner stems might contain less fibre than thicker stems, but it is less coarse fibre and so easier to ret, yielding more fibre. These authors also found that as row spacing increased, plant density within rows increased, which was found in this study as well. As well, Easson and Cooper (2002) found that reducing seeding rates lowered the fibre concentration in the straw, which also reflects the results achieved in this study. Lower plant densities would result in thicker individual plant stems, meaning a lower fibre concentration. The seeding rate results from this study also agree with Lafond's (1993) study, who found that plant density increased linearly with increasing seeding rate (with a seeding rate of up to 78 kg/ha).

In both years, CDC Mons produced the highest plant density, and Hermes the lowest in all three experiments (Tables 4.4, 4.8, and 4.12). In both 2004 and 2005 early and mid-May seeding resulted in the highest plant densities, while early-June seeding produced the lowest (Table 4.7). Lafond (1993) found that nitrogen fertilizer applications had a variable effect on plant density, where plant density was increased one year, but not in another. In this study, nitrogen fertilizer had no effect on plant density (Table 4.11). However, plant density was higher in 2005, which was unexpected as average plant densities were higher in 2004 for the seeding rate and row spacing as well as the seeding date experiment.

Plant density was either negatively correlated or not correlated at all with straw fibre concentration for all three experiments, both when Hermes was included as well as excluded from the data sets (Tables 4.5, 4.9, and 4.13). This is interesting since plant density is not correlated at all with straw fibre concentration in the seeding rate and row spacing experiment, which is the experiment that showed the greatest difference in plant density. This tentatively suggests that as plant density increases, straw fibre concentration decreases, which was not found in the seeding rate and row spacing experiment. Plant density was variably correlated with straw fibre yield in the three experiments (Tables 4.5, 4.9, and 4.13). In the seeding rate and row spacing experiment plant density was not correlated with straw fibre yield when Hermes was included in the data, and positively correlated without Hermes, while in the seeding date experiment plant density was negatively correlated with straw fibre yield when Hermes was included, and not correlated when Hermes was excluded from the data. In the nitrogen fertilizer experiment plant density and straw fibre yield were not correlated at all. These variable results do not illustrate a clear relationship between straw fibre yield and plant density.

Straw fibre concentration was strongly positively correlated with plant height for all three experiments, both when Hermes was included as well as excluded from the data (Tables 4.5, 4.9, and 4.13). This was expected as Hermes is a fibre flax cultivar, and so naturally taller than oilseed cultivars, as well as having a higher straw fibre concentration. In all experiments, Hermes was the tallest cultivar, and CDC Mons was the shortest, which is to be expected, since CDC Mons is typically a shorter oilseed flax cultivar. The fact that straw fibre concentration was strongly positively correlated when Hermes was excluded shows that Hermes did not have an influence on this correlation, and plant height is positively correlated with fibre concentration in the oilseed cultivars as well. This indicates that as the cultivars grow taller they would have higher straw fibre concentrations, or that taller genotypes have more fibre. However, when looking at the results from all three experiments, that trend is not clearly apparent, indicating that other factors were influencing straw fibre concentration.

The relationship between plant height and straw fibre yield is not as clear as with straw fibre concentration. When Hermes was included in the data, plant height was positively correlated with straw fibre yield in the seeding rate and row spacing as well as the seeding date experiment, and not correlated in the nitrogen fertilizer experiment (Tables 4.5, 4.9, and 4.13). When Hermes was excluded from the data, plant height was not correlated with straw fibre yield in the seeding rate and row spacing experiment, and negatively correlated in the seeding date and nitrogen fertilizer experiments. This is interesting, since it would be expected that as plants grew taller there would be a greater straw fibre yield. Yet this relationship was not clearly shown, especially when Hermes was excluded from the data and the oilseed cultivars alone were examined, as there is a negative relationship, meaning as plant height increases straw fibre yield decreases.

Row spacing had no effect in either year on plant height (Table 4.3). The highest seeding rate of 45kg/ha resulted in the shortest plants in both years, whereas the lowest seeding rate resulted in the tallest plants. These results correspond with Lafond's (1993) study, as well as Easson and Molloy's (2000), where plant height decreased with increasing seeding rate. The effect of seeding date on plant height was significant in 2004 (Table 4.7). That year, late-June seeding resulted in the tallest plants, followed by mid-May, and then early-May. Plants were shorter in 2005 than in 2004, which reflects the differences in growing seasons. Nitrogen fertilizer had no effect on plant height in either year (Table 4.11). Lafond (1993) found that nitrogen fertilizer had an inconsistent effect on plant height.

It is important to look at the relationship between seed yield, straw fibre concentration and fibre yield, as seed will still be the main economic product harvested from oilseed flax, and straw fibre will be a secondary product. Correlations for seed yield and straw fibre concentration were variable across the three experiments (Tables 4.5, 4.9, and 4.13). When Hermes was excluded from the data, in the seeding rate and row spacing and nitrogen fertilizer experiments, seed yield was not correlated with straw fibre concentration, but was positively correlated with straw fibre concentration in the seeding date experiment. When Hermes was included in the data, seed yield was negatively correlated with straw fibre concentration in all three experiments. Looking at the data, the effect of seed yield on straw fibre concentration is not clear, as the highest average seed yields sometimes occurred along with the greatest average straw fibre concentration, and sometimes the highest average seed yield was associated with lower straw fibre concentration.

This slightly complicates matters with regards to the CDC Flax Breeding Program, and breeders will need to decide which trait will be of greater economic importance since there is an unclear relationship between seed yield and straw fibre concentration. Seed yield will still be the primary economic product harvested from oilseed flax, and so the breeding program will most likely continue with practices that maximize seed yield. When the fibre flax cultivar Hermes is excluded from the data, there is either no correlation or a positive correlation between seed yield and straw fibre concentration. Therefore, continuing to breed for seed yield will most likely not decrease straw fibre concentration.

The highest seed yields were achieved in the 18 cm row spacing plots, and also at a seeding rate of 30 kg/ha (Table 4.3). These results coincide with research conducted by Gubbels and Kenaschuk (1989), who found their maximum seed yield at 30 kg/ha as well.

This study does not show a strong effect of seeding date on seed yield, but seeding any time after mid-May seems to either positively influence or have no negative effect on seed yield (Table 4.7). Grant et al. (2004) found that seed yield increased with increasing nitrogen application. That was not shown in this experiment, as nitrogen fertilizer did not have any effect on seed yield (Table 4.10). CDC Mons consistently produced the highest seed yield. It is interesting that CDC Mons produced high seed yield, as it had the highest plant density for both years, meaning that there would be less branching, and so possibly fewer capsules per plant. Seed yields were greater in 2004 than in 2005.

There is a negative correlation between seed yield and straw fibre yield both when Hermes is included as well as excluded from the data for the seeding date and the nitrogen fertilizer experiments (Tables 4.9, and 4.13). In the seeding rate and row spacing experiment, seed yield was negatively correlated with straw fibre yield when Hermes was included in the data, and not correlated without Hermes (Table 4.5). These results are important, as they show that seed yield should be decreasing if straw fibre yield is high. However, the data for the three experiments does not necessarily show this, as the treatments producing the highest straw fibre yield sometimes produced the highest seed yield as well. This suggests a weak and variable relationship between straw fibre yield and seed yield, and needs to be examined in future research.

Physiologically speaking, a negative correlation between seed yield and straw fibre yield is conceivable, as the majority of a plants resources are either going into the seed or the straw, not both. However, this is not necessarily reflected in these results. Straw processors would not be interested in a high seed yield, so this negative relationship is important in that regard.

Thousand seed weight was not affected by row spacing, seeding rate, seeding date, or nitrogen fertilizer application (Tables 4.2, 4.6, and 4.10). Thousand seed weight differed between cultivars in all three experiments. Vimy produced the highest thousand seed weight, while CDC Mons produced the lowest in all three experiments. Gubbels and Kenaschuk (1989) found that as seeding rate increased, seed weight decreased slightly, but those results were not found in these experiments. Thousand seed weights were higher in 2005, which is interesting since most plant characteristics for the three experiments had higher values in 2004.

Thousand seed weight was negatively correlated with straw fibre concentration for both the nitrogen fertilizer and seeding rate and row spacing experiment when Hermes was included as well as excluded from the data (Table 4.5, and 4.13). For the seeding date experiment, thousand seed weight was not correlated with straw fibre concentration at all, either when Hermes was included or excluded from the data (Table 4.9). Thousand seed weight was positively correlated with straw fibre yield in the nitrogen fertilizer trial both when Hermes was included as well as excluded from the data, whereas in the seeding date experiment thousand seed weight was not correlated with straw fibre yield either when Hermes was included or excluded from the data. For the seeding rate and row spacing experiment, thousand seed weight was positively correlated when Hermes was included, and not correlated when Hermes was excluded. These results suggest that thousand seed weight has a positive or no relationship with straw fibre yield, as well as a negative or nil relationship with straw fibre concentration.

Seed oil content was positively correlated with straw fibre concentration when Hermes was excluded from the data in all three experiments (Tables 4.5, 4.9 and 4.13). This is important to note as seed oil is an important economic product, and these results show that when breeding for higher straw fibre concentration, oil content will not be negatively affected in oilseed flax cultivars. This is beneficial with regards to the CDC Breeding Program, since any changes made in the program to increase straw fibre concentration need not lead to lower oil content. When Hermes was included, the correlations were variable. Oil content was negatively correlated with straw fibre concentration in the seeding rate and row spacing as well as seeding date experiment when Hermes was included. In the nitrogen fertilizer experiment, oil content was not correlated at all with straw fibre concentration when Hermes was included in the data. As Hermes is a fibre flax cultivar, and naturally has a lower oil content than oilseed flax, the influence of Hermes on the correlations is seen when it is included in the data set, and explains why cultivar was significant for each experiment with regards to straw fibre concentration.

Oil content was negatively correlated with straw fibre yield for all three experiments both when Hermes was included and excluded from the data (Tables 4.5, 4.9 and 4.13). These results imply that oil content would be lowered at high straw fibre yields. Among the three experiments, there was not a large range in oil content, and treatments with high straw fibre yields did not have the lowest oil contents. Even though a negative correlation was found between oil content and straw fibre yield in this study, data from the three experiments did not reflect this, as treatments with high straw fibre yields did not always result in the lowest oil contents. With regards to the CDC Breeding Program, it can tentatively be said that breeding for higher straw fibre yields would not effect oil content. However, more research to conclusively examine the association between oil content and straw fibre yield would be beneficial.

In all three experiments, the average oil content was not greatly affected by any of the agronomic conditions tested. Previous research conducted by Hocking et al. (1987) found that a higher nitrogen level reduced oil content, and found that high nitrogen levels may result in reduced oil yields despite increased seed yields. Those results were not shown in this study. Averaged over the two years, oil content ranged from 42.2% to 42.7% in the three experiments. This is important to the CDC Flax Breeding Program as the agronomic conditions tested in the three experiments to increase straw fibre concentration had no effect on oil content.

With regards to protein content, row spacing and seeding date had a significant effect in 2005 only, and seeding rate was not significant at all (Table 4.2 and 4.6). The 36 cm row spacing plots produced slightly higher protein in 2005, and the three seeding dates resulted in similar protein values. Grant et al. (2004) found that nitrogen fertilizer increased protein content and yield, which was not shown in this study as nitrogen fertilizer applications had no effect on protein content. Protein values were higher in 2005 for all three experiments, which was interesting as most plant and seed characteristic values were higher in the 2004 growing season. CDC Gold and Hermes produced similarly higher protein values, while Vimy and CDC Mons produced similarly lower protein values. This is interesting, as Hermes is a fibre flax cultivar, and one would assume that the oilseed cultivars would have higher protein values, as the seed is their primary economic resource. Yet similar results were achieved in the seeding rate and row spacing experiment as well as the nitrogen fertilizer experiment with regards to protein content.

Correlations between protein and straw fibre concentration were variable amongst the three experiments (Tables 4.5, 4.9 and 4.13). Protein was not correlated at all with straw fibre concentration for the seeding rate and row spacing experiment. For the seeding date experiment, protein was not correlated with straw fibre concentration when Hermes was excluded from the data, and positively correlated when Hermes was included in the data. In the nitrogen fertilizer experiment, protein content was negatively correlated with straw fibre concentration when Hermes was excluded from the data, and not correlated at all when Hermes was included in the data. These results do not clearly show a relationship between straw fibre concentration and protein content.

For the seeding rate and row spacing experiment as well as the seeding date experiment, protein content was positively correlated with straw fibre yield when Hermes was included in the data, and not correlated when Hermes was excluded. In the nitrogen fertilizer experiment, protein content was positively correlated with straw fibre yield both when Hermes was included and excluded from the data set. The influence of Hermes on these correlations is shown for two out of three experiments, as protein was positively correlated with straw fibre yield when Hermes was included, and not correlated without Hermes. When Hermes was excluded, there is no relationship between protein and straw fibre yield, or a positive one in the nitrogen fertilizer experiment. These results suggest that straw fibre yield can be targeted in the breeding program without any decrease in protein content.

6.0 Conclusions:

Based on the agronomic conditions investigated in this study, straw fibre concentration was optimized in oilseed flax when seeded at a 36 cm row spacing, at 30 or 45 kg/ha in mid-May. The 18 cm row spacing could also be used as there was only a slight increase in straw fibre concentration at the 36 cm row spacing. Nitrogen fertilizer applications had no effect on straw fibre concentration when nitrogen fertilizer was added to a soil with sufficient available nitrogen already present. These recommendations do not have any detrimental effects on other important oilseed flax characteristics such as seed yield, oil content and straw fibre yield. This is important to the CDC Flax Breeding Program since agronomic conditions that optimize straw fibre concentration can be implemented without negatively affecting the primary economic product of oilseed flax, which is the seed.

It is important to note that there was minimal or no interaction between any of the agronomic conditions tested for either cultivar, or straw fibre concentration. Therefore, the current field designs used in the CDC Flax Breeding Program can reasonably rank breeding lines within a test, as well as compare cultivar rankings from different tests.

Since the cultivars were ranked in the same order from highest to lowest straw fibre concentration for all three experiments in both years, the protocol used with the NIR instrument is given a great deal of credibility. Of the oilseed cultivars tested, CDC Gold and Vimy would be better choices for future studies focusing on increasing straw fibre concentration rather than CDC Mons, which consistently produced the lowest straw fibre concentration.

Straw fibre yield was fairly constant for the three experiments as well. In 2005 Hermes consistently produced the highest straw fibre yield, CDC Mons in the middle, with CDC Gold and Vimy producing the lowest straw fibre yield for all three experiments. Row spacing had no effect on straw fibre yield, while straw fibre yield increased with increasing seeding rate. Early to mid-May seeding gave the highest straw fibre yields, and again, nitrogen fertilizer had no effect.

CDC Mons consistently produced the highest plant density for all three experiments, while Hermes always was the lowest in both years of the study. The 36 cm row spacing resulted in higher plant densities, and plant density increased with increasing seed rate. Early to mid-May seeding resulted in the highest plant densities as well. Nitrogen fertilizer had no effect on plant density.

Hermes was the tallest of the four cultivars in all three experiments, and CDC Mons was the shortest. Row spacing had no effect, and plant height decreased with increasing seeding rate. Plants were taller when seeded later, with early-June seeding resulting in the tallest plants. Nitrogen fertilizer applications had no effect on plant height.

CDC Mons consistently produced the highest seed yield in all three experiments, whereas Hermes always was the lowest yielding in both years. The 18 cm row spacing resulted in higher seed yields than the 36 cm row spacing, while the middle seed rate of 30 kg/ha produced the highest seed yield. This is beneficial to the CDC Breeding Program since straw fibre concentration was also optimized at a higher seed rate of 30 or 45 kg/ha, and at either row spacing. The agronomic conditions used to optimize straw fibre concentration can be employed without negatively affecting seed yield in oilseed flax. Seeding date had no strong effect on seed yield, seeding in mid-May resulted in the highest seed yield in both years, but differences were not significant. There was no effect on seed yield from applications of nitrogen fertilizer.

The results from the thousand seed weight tests were variable, but CDC Mons generally had the lowest thousand seed weight, with the other three cultivars having similar thousand seed weights. There was no conclusive effect from row spacing, seeding rate, seeding date, or nitrogen fertilizer application on thousand seed weight.

Hermes consistently produced the lowest oil content, while the other three oilseed cultivars produced similar oil contents in all three experiments in both years of the study. Row spacing, seeding rate, seeding date, and nitrogen fertilizer had no definite effect on seed oil content. This is important with regards to the CDC Flax Breeding Program, as agronomic practices can be varied in order to optimize straw fibre concentration without negatively affecting oil content in the seed.

In both years for the three experiments, CDC Gold and Hermes produced higher protein contents, whereas Vimy and CDC Mons produced lower protein contents. There was no decisive effect from row spacing, seeding rate, seeding date or nitrogen fertilizer application on protein content. Again, this is important with regards to the CDC Flax

Breeding Program as straw fibre concentration can be targeted without decreasing protein value.

The economically important plant and seed characteristics that were tested in this study showed great consistency over the two years of these experiments, which lends strength to the findings from this research. Straw fibre concentration as well as straw fibre yield can be targeted in future oilseed flax breeding research without decreasing any character of economic importance such as seed yield, oil or protein content.

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8.0 Appendix:

8.1 Seeding Rate and Row Spacing

Table 8.1.1: Analysis of Variance of seeding rates, row spacings and varieties for flax plant density (plants/m^2).

	Source	DF	Mean Square	F Value	P > F
2004	Error	46	32751.52		
	Rep	2	28468.48	0.87	0.4260
	Rowsp	1	2665267.18	81.38	<.0001*
	Srate	2	2357372.67	71.98	<.0001*
	Variety	3	807794.49	24.66	<.0001*
	Rowsp x srate	2	259643.58	7.93	0.0011*
	Srate x variety	6	102832.53	3.14	0.0115*
	Rowsp x variety	3	134514.85	4.11	0.0116*
	Rowsp x sratex variety	6	36908.96	1.13	0.3619
2005					
	Error	46	1116972.19		
	Rep	2	14720.46	0.61	0.5497
	Rowsp	1	1195960.00	49.25	<.0001*
	Srate	2	1317472.74	54.26	<.0001*
	Variety	3	308510.12	12.71	<.0001*
	Rowsp x srate	2	116138.72	4.78	0.0130*
	Srate x variety	6	52277.46	2.15	0.0651
	Rowsp x variety	3	66560.28	2.74	0.0539
	Rowsp x srate x variety	6	84795.78	3.49	0.0063*

Table 8.1.2: Analysis of Variance of seeding rates, row spacings and varieties for flax plant height (cm).

	Source	DF	Mean Square	F Value	P > F
2004	Error	46	34.34		
	Rep	2	90.93	2.65	0.0816
	Rowsp	1	2.14	0.06	0.8042
	Srate	2	156.40	4.55	0.0157*
	Variety	3	3034.03	88.36	<.0001*
	Rowsp x srate	2	30.02	0.87	0.4240
	Srate x variety	6	7.55	0.22	0.9685
	Rowsp x variety	3	39.76	1.16	0.3361
	Rowsp x srate x variety	6	31.28	0.91	0.4955
2005					
	Error	46	15.77		
	Rep	2	30.71	1.95	0.1542
	Rowsp	1	7.67	0.49	0.4891
	Srate	2	111.86	7.09	0.0021*
	Variety	3	3401.82	215.71	<.0001*
	Rowsp x srate	2	15.76	1.00	0.3760
	Srate x variety	6	14.86	0.94	0.4742
	Rowsp x variety	3	27.83	1.76	0.1671
	Rowsp x srate x variety	6	14.28	0.91	0.4994

Table 8.1.3: Analysis of Variance of seeding rates, row spacings and varieties on average flax stem fibre concentration.

	Source	DF	Mean Square	F Value	P > F
2004	Error	46	2.11		
	Rep	2	0.28	0.13	0.8741
	Rowsp	1	20.08	9.52	0.0034*
	Srate	2	12.62	5.98	0.0049*
	Variety	3	60.83	28.84	<.0001*
	Rowsp x srate	2	2.35	1.11	0.3367
	Srate x variety	6	5.78	2.74	0.0231*
	Rowsp x variety	3	0.54	0.26	0.8553
	Rowsp x srate x variety	6	1.62	0.77	0.5980
2005					
	Error	46	0.67		
	Rep	2	0.53	0.80	0.4566
	Rowsp	1	3.54	5.29	0.0261*
	Srate	2	31.87	47.54	<.0001*
	Variety	3	45.79	68.32	<.0001*
	Rowsp x srate	2	0.67	0.98	0.3824
	Srate x variety	6	1.29	1.93	0.0957
	Rowsp x variety	3	1.61	2.40	0.0800
	Rowsp x srate x variety	6	1.35	2.01	0.0831

Table 8.1.4: Analysis of Variance of seeding rates, row spacings and varieties on average straw fibre yield (kg) per plot.

	Source	DF	Mean Square	F Value	P > F
2005	Error	46	1.50		
	Rep	2	2.47	1.65	0.2031
	Rowsp	1	0.26	0.17	0.6798
	Srate	2	50.06	33.48	<.0001*
	Variety	3	108.28	72.42	<.0001*
	Rowsp x srate	2	0.01	0.01	0.9905
	Srate x variety	6	0.42	0.28	0.9427
	Rowsp x variety	3	4.93	3.30	0.0285*
	Rowsp x srate x variety	6	1.66	1.11	0.3702

Table 8.1.5: Analysis of Variance of seeding rates, row spacings and varieties on seed yield (kg/ha).

	Source	DF	Mean Square	F Value	P > F
2004	Error	46	31074.34		
	Rep	2	54685.63	1.76	0.1835
	Rowsp	1	326378.14	10.50	0.0022*
	Srate	2	28750.881	0.93	0.4037
	Variety	3	917355.03	29.52	<.0001*
	Rowsp x srate	2	6852.72	0.22	0.8029
	Srate x variety	6	17271.32	0.56	0.7629
	Rowsp x variety	3	28311.38	0.91	0.4430
	Rowsp x srate x variety	6	34691.29	1.12	0.3677
2005					
	Error	46	8441.32		
	Rep	2	25215.08	2.99	0.0603
	Rowsp	1	638318.17	75.62	<.0001*
	Srate	2	29186.68	3.46	0.0399*
	Variety	3	1068336.91	126.56	<.0001*
	Rowsp x srate	2	7907.44	0.94	0.3992
	Srate x variety	6	2054.47	0.24	0.9596
	Rowsp x variety	3	75911.01	8.99	<.0001*
	Rowsp x srate x variety	6	12289.24	1.46	0.2145

Table 8.1.6: Analysis of Variance of seeding rates, row spacings and varieties on thousand seed weight (g).

	Source	DF	Mean Square	F Value	P > F
2004	Error	46	0.06		
	Rep	2	0.16	2.79	0.0720
	Rowsp	1	0.05	0.77	0.3835
	Srate	2	0.14	2.34	0.1078
	Variety	3	0.37	6.28	0.0012*
	Rowsp x srate	2	0.09	1.45	0.2458
	Srate x variety	6	0.09	1.53	0.1885
	Rowsp x variety	3	0.02	0.32	0.8110
	Rowsp x srate x variety	6	0.06	1.02	0.4241
2005					
	Error	46	0.57		
	Rep	2	0.61	4.15	0.0221*
	Rowsp	1	0.07	0.47	0.4960
	Srate	2	0.04	0.31	0.7381
	Variety	3	2.91	19.82	<.0001*
	Rowsp x srate	2	0.43	2.90	0.0649
	Srate x variety	6	0.35	2.37	0.0442*
	Rowsp x variety	3	0.17	1.19	0.3249
	Rowsp x srate x variety	6	0.11	0.73	0.6308

Table 8.1.7: Analysis of Variance of seeding rates, row spacings and varieties on seed oil content.

	Source	DF	Mean Square	F Value	P > F
2004					
	Error	46	1.5807911		
	Rep	2	2.2418056	1.42	0.2525
	Rowsp	1	0.6234722	0.39	0.5331
	Srate	2	0.3593056	0.23	0.7976
	Variety	3	62.2001389	39.35	<.0001*
	Rowsp x srate	2	0.8343056	0.53	0.5934
	Srate x variety	6	0.6954167	0.44	0.8483
	Rowsp x variety	3	0.5145833	0.33	0.8069
	Rowsp x srate x variety	6	1.8926389	1.20	0.3248
2005					
	Error	46	0.2860145		
	Rep	2	0.7350000	2.57	0.0875
	Rowsp	1	1.4450000	5.05	0.0294*
	Srate	2	0.0529167	0.19	0.8317
	Variety	3	98.4825926	344.33	<.0001*
	Rowsp x srate	2	0.2529167	0.88	0.4199
	Srate x variety	6	0.1549537	0.54	0.7737
	Rowsp x variety	3	0.0757407	0.26	0.8504
	Rowsp x srate x variety	6	0.1886574	0.66	0.6823

Table 8.1.8: Analysis of Variance of seeding rates, row spacings and varieties on seed protein content.

	Source	DF	Mean Square	F Value	P > F
2004					
	Error	46	1.6436171		
	Rep	2	2.6268056	1.60	0.2133
	Rowsp	1	2.0672222	1.26	0.2679
	Srate	2	0.2222222	0.14	0.8739
	Variety	3	92.0850000	56.03	<.0001*
	Rowsp x srate	2	1.9105556	1.16	0.3217
	Srate x variety	6	0.4977778	0.30	0.9323
	Rowsp x variety	3	0.9057407	0.55	0.6500
	Rowsp x srate x variety	6	1.4512963	0.88	0.5150
2005					
	Error	46	0.2696196		
	Rep	2	1.6154167	5.99	0.0049*
	Rowsp	1	2.2755556	8.44	0.0056*
	Srate	2	0.1212500	0.45	0.6406
	Variety	3	119.5353704	443.35	<.0001*
	Rowsp x srate	2	0.4393056	1.63	0.2072
	Srate x variety	6	0.2560648	0.95	0.4694
	Rowsp x variety	3	0.2355556	0.87	0.4616
	Rowsp x srate x variety	6	0.3226389	1.20	0.3251

8.2 Seeding Date

Table 8.2.1: Analysis of Variance of seeding dates and varieties on flax plant density (plants/m^2).

	Source	DF	Mean Square	F Value	P > F
2004	Error	18	4768.78		
	Rep	2	11419.19	5.56	0.0700
	Sdate	2	26798.24	13.05	0.0177*
	Rep x sdate	4	2053.14	0.43	0.7847
	Variety	3	64968.72	13.62	<.0001*
	Sdate x variety	6	8895.38	1.87	0.1426
2005					
	Error	18	5212.24		
	Rep	2	26426.96	5.41	0.0728
	Sdate	2	52825.57	10.82	0.0244*
	Rep x sdate	4	4884.01	0.94	0.4649
	Variety	3	121382.72	23.29	<.0001*
	Sdate x variety	6	8311.67	1.59	0.2059

Table 8.2.2: Analysis of Variance of seeding dates and varietes on flax plant height (cm).

	Source	DF	Mean Square	F Value	P > F
2004	Error	18	7.50		
	Rep	2	1.36	0.28	0.7702
	Sdate	2	146.79	30.17	<.0039*
	Rep x sdate	4	4.87	0.65	0.6351
	Variety	3	1536.50	204.81	<.0001*
	Sdate x variety	6	7.30	0.97	0.4707
2005					
	Error	18	2.43		
	Rep	2	26.32	1.94	0.2577
	Sdate	2	66.71	4.92	0.0836
	Rep x sdate	4	13.57	5.58	0.0042*
	Variety	3	1644.28	676.48	<.0001*
	Sdate x variety	6	19.23	7.91	0.0003*

Table 8.2.3: Analysis of Variance of seeding dates and varieties on average flax stem fibre concentration.

	Source	DF	Mean Square	F Value	P > F
2004	Error	18	0.38		
	Rep	2	0.40	1.71	0.2907
	Sdate	2	4.84	20.54	0.0079*
	Rep x sdate	4	0.24	0.63	0.6483
	Variety	3	20.82	55.51	<.0001*
	Sdate x variety	6	1.90	5.06	0.0033*
2005					
	Error	18	0.19		
	Rep	2	0.23	1.37	0.3516
	Sdate	2	5.76	33.74	<.0031*
	Rep x sdate	4	0.17	0.91	0.4814
	Variety	3	36.47	193.44	<.0001*
	Sdate x variety	6	0.29	1.55	0.2177

Table 8.2.4: Analysis of Variance of seeding dates and varieties on average straw fibre yield (kg) per plot.

	Source	DF	Mean Square	F Value	P > F
2005	Error	18	1.07		
	Rep	2	3.36	8.39	0.0370*
	Sdate	2	4.08	10.20	0.0269*
	Rep x sdate	4	0.40	0.37	0.8236
	Variety	3	23.68	22.19	<.0001*
	Sdate x variety	6	0.62	0.58	0.7429

Table 8.2.5: Analysis of Variance of seeding dates and varieties on seed yield.

	Source	DF	Mean Square	F Value	P > F
2004	Error	18	7622.22		
	Rep	2	30842.15	4.72	0.0885
	Sdate	2	76311.89	11.69	0.0213*
	Rep x sdate	4	6528.57	0.86	0.5084
	Variety	3	499166.83	65.49	<.0001*
	Sdate x variety	6	3833.23	0.50	0.7981
2005					
	Error	18	4440.72		
	Rep	2	6119.05	3.16	0.1502
	Sdate	2	3337.62	1.72	0.2884
	Rep x sdate	4	1935.91	0.44	0.7809
	Variety	3	458351.71	103.22	<.0001*
	Sdate x variety	6	8046.85	1.81	0.1532

Table 8.2.6: Analysis of Variance of seeding dates and varieties on thousand seed weight (g).

	Source	DF	Mean Square	F Value	P > F
2004	Error	18	0.18		
	Rep	2	0.38	1.97	0.2536
	Sdate	2	0.36	1.86	0.2678
	Rep x sdate	4	0.19	1.04	0.4148
	Variety	3	1.74	9.42	0.0006*
	Sdate x variety	6	0.26	1.40	0.2673
2005					
	Error	18	0.14		
	Rep	2	0.47	2.32	0.2146
	Sdate	2	0.10	0.48	0.6511
	Rep x sdate	4	0.20	1.47	0.2538
	Variety	3	0.53	3.80	0.0285*
	Sdate x variety	6	0.17	1.25	0.3266

Table 8.2.7: Analysis of Variance of seeding dates and varieties on seed oil content.

	Source	DF	Mean Square	F Value	P > F
2004					
	Error	18	0.0471296		
	Rep	2	0.0036111	0.25	0.7901
	Sdate	2	0.3286111	22.75	0.0065*
	Rep x sdate	4	0.0144444	0.31	0.8698
	Variety	3	56.3518519	1195.68	<.0001*
	Sdate x variety	6	0.1226852	2.60	0.0539
2005					
	Error	18	0.0701852		
	Rep	2	0.4800000	6.78	0.0519
	Sdate	2	1.3908333	19.64	0.0085*
	Rep x sdate	4	0.0708333	1.01	0.4287
	Variety	3	60.8870370	867.52	<.0001*
	Sdate x variety	6	0.0600926	0.86	0.5446

Table 8.2.8: Analysis of Variance of seeding dates and varieties on seed protein content.

	Source	DF	Mean Square	F Value	P > F
2004					
	Error	18	0.0917593		
	Rep	2	0.0336111	0.39	0.7023
	Sdate	2	0.1119444	1.29	0.3701
	Rep x sdate	4	0.0869444	0.95	0.4595
	Variety	3	51.2614815	558.65	<.0001*
	Sdate x variety	6	0.2756481	3.00	0.0326*
2005					
	Error	18	0.0585185		
	Rep	2	0.3358333	6.06	0.0616
	Sdate	2	2.8308333	51.08	0.0014*
	Rep x sdate	4	0.0554167	0.95	0.4598
	Variety	3	62.3114815	1064.82	<.0001*
	Sdate x variety	6	1.0945370	18.70	<.0001*

8.3 Nitrogen Fertilizer

Table 8.3.1: Analysis of Variance of nitrogen fertilizer rates and varieties on flax plant density (plants/m^2).

	Source	DF	Mean Square	F Value	P > F
2004					
	Error	30	4468.05		
	Rep	2	6269.88	1.40	0.2615
	Variety	3	133206.66	29.81	<.0001*
	Nrate	3	4912.89	1.10	0.3646
	Variety x nrate	9	1464.70	0.33	0.9589
2005					
	Error	30	3920.04		
	Rep	2	1820.40	0.46	0.6330
	Variety	3	97324.50	24.83	<.0001*
	Nrate	3	2669.05	0.68	0.5707
	Variety x nrate	9	6749.90	1.72	0.1274

Table 8.3.2: Analysis of Variance of nitrogen fertilizer rates and varieties on flax plant height.

	Source	DF	Mean Square	F Value	P > F
2004					
	Error	30	5.35		
	Rep	2	30.64	5.73	0.0078*
	Variety	3	2011.63	376.12	<.0001*
	Nrate	3	5.42	1.01	0.4008
	Variety x nrate	9	1.72	0.32	0.9616
2005					
	Error	30	5.24		
	Rep	2	1.18	0.23	0.7997
	Variety	3	1839.60	350.91	<.0001*
	Nrate	3	9.50	1.81	0.1663
	Variety x nrate	9	3.42	0.65	0.7434

Table 8.3.3: Analysis of Variance of nitrogen fertilizer rates and varieties on average stem fibre concentration.

	Source	DF	Mean Square	F Value	P > F
2004	Error	30	1.16		
	Rep	2	0.28	0.24	0.7892
	Variety	3	46.16	39.78	<.0001*
	Nrate	3	1.04	0.90	0.4546
	Variety x nrate	9	1.14	0.98	0.4740
2005					
	Error	30	0.82		
	Rep	2	0.27	0.33	0.7244
	Variety	3	43.49	52.87	<.0001*
	Nrate	3	0.88	1.08	0.3743
	Variety x nrate	9	0.33	0.40	0.9236

Table 8.3.4: Analysis of Variance of nitrogen fertilizer rates and varieties on average straw fibre yield (kg) per plot.

	Source	DF	Mean Square	F Value	P > F
2005	Error	30	0.86		
	Rep	2	2.33	2.72	0.0824
	Variety	3	30.98	36.03	<.0001*
	Nrate	3	0.49	0.57	0.6409
	Variety x nrate	9	0.53	0.62	0.7712

Table 8.3.5: Analysis of Variance of nitrogen fertilizer rates and varieties on seed yield.

	Source	DF	Mean Square	F Value	P > F
2004	Error	30	4823.06		
	Rep	2	5745.23	1.19	0.3178
	Variety	3	1093708.01	226.77	<.0001*
	Nrate	3	5051.86	1.05	0.3859
	Variety x nrate	9	9653.06	2.00	0.0747
2005					
	Error	30	5507.57		
	Rep	2	111780.57	20.30	<.0001*
	Variety	3	921584.95	167.33	<.0001*
	Nrate	3	9322.21	1.69	0.1897
	Variety x nrate	9	1617.23	0.29	0.9711

Table 8.3.6: Analysis of Variance of nitrogen fertilizer rates and varieties on thousand seed weight.

	Source	DF	Mean Square	F Value	P > F
2004	Error	30	0.08		
	Rep	2	0.02	0.19	0.8252
	Variety	3	1.16	14.29	<.0001*
	Nrate	3	0.06	0.75	0.5317
	Variety x nrate	9	0.04	0.48	0.8758
2005					
	Error	30	0.12		
	Rep	2	0.24	1.97	0.1568
	Variety	3	1.85	15.22	<.0001*
	Nrate	3	0.08	0.62	0.6062
	Variety x nrate	9	0.09	0.72	0.6833

Table 8.3.7: Analysis of Variance of nitrogen fertilizer rates and varieties on seed oil content.

	Source	DF	Mean Square	F Value	P > F
2004	Error	30	0.0882037		
	Rep	2	0.1518750	1.72	0.1959
	Variety	3	88.0907639	998.72	<.0001*
	Nrate	3	0.1027701	1.17	0.3394
	Variety x nrate	9	0.1664068	1.89	0.0931
2005					
	Error	30	0.0916111		
	Rep	2	0.1158333	1.26	0.2970
	Variety	3	73.5613194	802.97	<.0001*
	Nrate	3	0.0952083	1.04	0.3894
	Variety x nrate	9	0.0333565	0.36	0.9433

Table 8.3.8: Analysis of Variance of nitrogen fertilizer rates and varieties on seed protein content.

	Source	DF	Mean Square	F Value	P > F
2004	Error	30	0.4740215		
	Rep	2	1.0002083	2.11	0.1389
	Variety	3	84.4213194	178.10	<.0001*
	Nrate	3	0.7583141	1.60	0.2101
	Variety x nrate	9	0.5877588	1.24	0.3089
2005					
	Error	30	0.0831528		
	Rep	2	0.1093750	1.32	0.2834
	Variety	3	55.4068750	666.33	<.0001*
	Nrate	3	0.0307639	0.37	0.7752
	Variety x nrate	9	0.1240972	1.49	0.1959