An integrated approach to investigating the reintroduction of flax production in Iowa

by

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CHAPTER I

General introduction

Flax (*Linum usitatissimum*) is considered the earliest oil and fiber crop. It was the primary source for these goods during prehistoric times. Flax was part of the ‘Neolithic package’ of crops domesticated in the Near East around 10,000 years ago (Zohary, 2000). Current cultivated varieties of flax have been categorized into broadly defined groups of ‘oil’ varieties and ‘fiber’ varieties. Significant fiber flax production takes place in France, the Soviet Union and Poland (AURI, 2003); while oilseed production occurs in Canada and the United States (Berglund and Zollinger, 2002). Oil varieties usually measure between 30 and 90 cm (12 to 36 in.) tall and have large seeds with an average oil content of 40% (Zohary, 2000). Fiber varieties are usually taller, measuring up to 120 cm (47 in.), have fewer tillers, and smaller and fewer seeds compared to the oilseed varieties (Fu et al., 2002).

Flax is well known for its unique fatty acid profile, specifically, the high content of alpha linolenic acid (ALA), which typically ranges between 45% and 65% of the total oil of the seed (Vrinten et al., 2005). Fatty acids are organic compounds comprising raw food ingredients and industrial products. Common fatty acids found in foods are palmitic acid (16:0, saturated), stearic acid (18:0, saturated), oleic acid (18:1, monounsaturated), linoleic acid (18:2, polyunsaturated) and ALA (18:3, polyunsaturated). Alpha linolenic acid is an essential 18-carbon fatty acid that cannot be synthesized by animal tissue. Fatty acids are named based on the position of the first double carbon bond in the carbon chain counting from the methyl end (Morris, 2003).

Due to flax's high percentage of ALA, until the 1940s, flax was used for industrial products and commonly referred to as linseed oil. When oil containing high levels of ALA is exposed to oxygen, it forms a tough, elastic film, which will dry rapidly. This characteristic was ideal for the paint and linoleum industries, which boomed during WWII. Linseed oil was in high demand to mix as the drying agent in paint used to paint military vehicles. The process, by which the oil was expelled, either by hydraulically pressing the seeds or through heat extraction, left a cake, consisting of hulls, some oil, and 30-40% crude protein. This was an ideal source of protein cakes for livestock overseas (Green and Marshall, 1981).

In response to the WWII demand, flax acreage in the U.S. peaked at 2,300,000 ha (5,691,000 A) harvested in 1943. In 1949, half of U.S. flax production was in Minnesota, with 606,000 ha (1,500,000 A) planted (NASS, 2006). Since the 1890s, University of Minnesota (UM) has researched and developed new flax varieties and established the world center for flax testing at the UM Agricultural Experiment Station (UM AES). Until 1972, the UM AES maintained thousands of accessions from the world germplasm collection (Hardman and Hanson, 2003). The decrease in linseed demand after WWII was affected by increased use of latex paints, which used synthetic drying agents. In addition, planting soybeans increased in popularity because of the plant's ability to fix nitrogen, thereby benefiting the production of maize. By 1970, only four states: Minnesota, Montana, North Dakota and South Dakota harvested flax from more than 4,000 ha (10,000 A) (NASS, 2006).

Today, flax used for human consumption is commonly referred to as flaxseed oil. Its demand has increased with the recent documentation of the importance of n-3 fatty acids in human diets. Alpha linolenic acid is a type of n-3 fatty acid which is a precursor to docosahexaenoic acid (DHA 22:6) another essential polyunsaturated fatty acid. In 2000, a review of 38 articles from the health field indicated that these n-3 fatty acids may prevent or positively influence the following diseases: coronary heart disease and stroke; essential fatty acid deficiency in infancy during retinal and brain development; autoimmune disorders such as lupus and nephropathy; Crohn's disease; cancers of the breast, colon and prostate; mild hypertension; and rheumatoid arthritis (Connor, 2000).

Production of flaxseed has increased in the upper Midwestern U.S. due to this rise in human consumption and with the recent construction of a certified organic oilseed expelling facility in northwestern Iowa. In 2004, organic grain producers in Iowa began experimenting with flax on approximately 40 ha (100 A). In 2005, Iowa State University (ISU) initiated flax research on ISU and UM experimental research stations and with on-farm cooperators from both states (Minnesota data are not reported in this thesis.)

Thesis Organization

Chapter one consists of an overview of the history of flaxseed production and its uses until the present, and a description of the contents of this thesis. Chapter two is a literature review comprised of relevant literature specific to each project conducted. Chapter three, which describes the planting date and cultivar study, and chapter four, which describes the weed management study, are papers to be submitted for publication in a referred agronomic journal. Chapter five describes interviews conducted in 2005 with the four farmer cooperators from Iowa. Chapters six, seven and eight are summaries of the planting rate study, the on-farm agronomic research and the straw quality analysis, respectively. Chapter nine is a general conclusion that summarizes the outcome of the data collected and discusses the relevance of the results. Finally, an appendix is provided with supplemental data not presented in the body of this thesis.

Literature Cited

Ag Utilization Research Institute (AURI). 2003. Flax: blue flowers, seeds of gold. Ag Innovation News July-Aug 2003. Accessed online on 11/17/2007 at http://www.auri.org/news/ainjul03/12flax.htm.

Berglund, D., and R. Zollinger. 2002. Flax production in North Dakota. Extension Publication A-1038. North Dakota State University Extension.

Connor, W. 2000. Importance of n-3 fatty acids in health and disease. American Journal of Clinical Nutrition 71:171S-175S.

Fu, Y., A. Diederichsen, K. Richards, and G. Peterson. 2002. Genetic diversity within a range of cultivars and landraces of flax (*Linum usitatissimum* L.) as revealed by RAPDs. Genetic Resources and Crop Evolution 49:167-174.

Green, A.G., and D.R. Marshall. 1981. Variation for oil quantity and quality in linseed (*Linum usitatissimum*). Aust J Agric Res. 32:599-607.

Hardman, L., and D. Hanson. 2003. Food for life. Accessed online on 11/16/2007 at http://www.maes.umn.edu/components/7658-8.asp.

Morris, D. 2003. Flax-a health and nutrition primer. Winnipeg, Manitoba: Flax Council of Canada.

National Agriculture Statistics Service (NASS). 2006. Accessed online on 11/16/2007 at http://www.nass.usda.gov/QuickStats/index2.jsp.

Vrinten, P., Z. Hu, M. A. Munchinsky, G. Rowland, and X. Qiu. 2005. Two *FAD3* desaturase genes control the level of linolenic acid in flax seed. Plant Phy. 139:79-87.

Zohary, M.H. 2000. Domestication of plants in the Old World. 3rd ed. Oxford University Press, Oxford.

CHAPTER II

Literature review

Introduction

Flax is an annual, dicot forb that is self-pollinating with 0.3% to 2% outcrossing, occurring mainly due to insects. The plant's life cycle requires a 45-to 60-day vegetative stage, a 15-to 25-day flowering stage and a 30-to 40-day maturation stage. All stages can be shortened due to high temperatures (>32 C (90 F)) for extended periods of time, low moisture annual precipitation (<38 cm (15 in.) or the incidence of disease (Berglund and Zollinger, 2002).

The plant has one main stem and will branch at low populations. The stem terminates in a multi-branched inflorescence with blue and white colored flowers. Flower parts, petals, sepals and anthers all occur in groups of five. After a flower blooms it typically is shed, although some flowers have been observed to bloom more than once, sometimes due to periods of heat stress (Cross et al., 2003). On warm, clear days, flowers open just after sunrise and petals are usually shed by early afternoon. After flowering, bolls begin to form. Bolls are the capsules or pods which hold the seed. A complete boll can have up to ten seeds; however, most will average about six seeds. Bolls ripen 20 to 25 days following flowering and change from a yellow, green color to a dark tan or brown color when the seeds and bolls are physiologically mature. When mature, the sections of the boll will gape open slightly and the seed will rattle inside the boll when shaken. The seed can be brown, golden or yellow and is covered with a mucilaginous coating that makes it shiny. Upon contact with water the seed becomes sticky and can stick to the boll surface resulting in a scabby appearance or loss of shine. The seed is flat and oval with a pointed tip. It measures about 2.5 x 5.0 x 1.5 mm (0.09 x 0.2 x 0.06 in.) in size.

The composition of the seed is rich in fat, protein and dietary fiber. Brown flaxseed averages 41% oil, 20% protein, 28% total dietary fiber, 7.7% moisture and 3.4% ash. Oil and protein content are inversely correlated (Hopper and Nesbitt, 1935). In addition to a high percentage of total oil content, flax has unique oil quality characteristics which were described in chapter 1.

Historically, flax has been grown in North Dakota, Montana, northern Minnesota, and Canada due to favorable climate conditions for the production of high oil content with a highly unsaturated fatty acid profile. In these regions, annual rainfall can range from 76 cm (30 in.) in Minnesota to 38 cm (15 in.) in eastern Montana. The majority of rain falls in this region between April and June (Oplinger et al; 1997). Also, temperatures during the growing season can range from 11 C (53 F) to 23 C (73 F). The growing season of the upper Great Plains area averages four to five months from mid-May until the first frost usually-mid-September (USGS, 2006). The majority of North American flax cultivars have been bred and selected from these environments. Since seed attributes are affected by temperature during plant growth and development, cultivar selection, crop production techniques and seed conditioning; flax grown outside of these regions could result in differing yield potential and seed quality characteristics. In addition, the incorporation of this crop into a farming system is highly dependent on the crop’s ability to achieve comparable profits to other cash grains in the system. Critical understanding not only of its agronomic performance but also its adaptability will increase its success and acceptance on the Iowa landscape.

Planting date

It is well documented that as temperature increases to a certain threshold during plant development, the stages of plant growth are accelerated (Berry and Bjorkman, 1980). The later a crop is planted during the spring sowing season, the more likely it will develop during warmer temperatures and longer photoperiods common to the summer months in the Midwest. These warmer temperatures hasten flax plant growth and development but the later planting date depresses yield.

Flax growth will occur during warmer summer month temperatures if it is planted later in the spring. At the University of Wales, in the United Kingdom, flax cultivar, 'Tomba', was planted on eight different dates-every two weeks between 1 March 1999 and 7 June 1999 at the University of Wales for a total of eight planting date treatments. This study concluded that with a delayed sowing date, the number of days between developmental stages decreased. An overall decrease in yield occurred with the later dates, due to decreases in all yield components. Fewer bolls per plant, fewer seeds per boll, and lower seed weights were recorded. Straw weight was similar between the first three planting dates but was significantly lower after the fourth planting date and all subsequent planting dates. Harvest index percentage decreased significantly with a later date (Siddique et al., 2002). In another study conducted in Canada, shoot formation and boll maturity were accelerated when temperatures increased from 16 C (60 F) to 21 C (70F). Additionally, the numbers of seeds per boll and seed weight were decreased (Dybing and Zimmerman, 1965). Three more studies from India, Italy and Bangladesh concluded that a delayed planting date resulted in a decrease in flaxseed yield (Dixit et al., 1994; Fontana et al., 1996; Shahidullah et al., 1997). Other researchers have found similar planting date effects on yield components of Kentucky bluegrass (Peterson and Loomis, 1949; Lindsey and Peterson, 1964) and orchardgrass (Gardner and Loomis, 1953).

Flax at flowering and seed set are sensitive to temperatures in excess of 25 C (77 F) for extended periods (Dillman and Hopper, 1943; Painter et al., 1944; Ford and Zimmerman, 1964). These developmental stages are critical for the development of sink structures for seed production. Flaxseed set was reduced with temperatures warmer than 25 C (77 F). Partial necrosis of the ovule occurred after one day of exposure to 31 C (88 F) and complete necrosis occurred after a five-day exposure to 31 C (88 F) (Kraft et al., 1963). In 1996, four cultivars out of six studied had reduced yields following a five-day exposure to a heat stress reaching 40 C (104 F) each day at flowering. The other two cultivars had reduced yields after a seven-day exposure under the same stress conditions (Gusta et al., 1997).

In a variety of species, high temperatures, defined as >10 C (50 F) above the normal growing temperature, cause heat stress and affect reproductive development such as: pollen meiosis, pollen germination, ovule development, ovule viability, development of the embryo (Peet et al., 1998) and seedling growth (Hong and Vierling, 2001). Bean, maize and groundnut were more susceptible to day-or night-time high temperatures during later flowering and early seed development (Cross et al., 2003). Specifically, seed set in maize was affected by high temperatures during pollination (Herrero and Johnson, 1980). Fruit production was reduced in tomato, avocado, wheat and common bean when heat stress periods occurred during the daytime or nighttime of the flowering stage.

Cross et al. (2003) studied flax to assess plant development under heat stressed conditions (>10 C [50 F]) above normal growing temperatures). To alleviate potential drought stress, all plants were well watered. Plants were exposed to extended periods of heat stress for seven days (7dhs) or 14 days (14 dhs). Flower production was not affected by these treatments; however, the length of the flowering period was extended 11 and 15 days longer than the control plots in the 7 dhs and 14 dhs treatments, respectively, due to compensatory flowering. This longer duration resulted in greater total flower numbers; however, the conversion rate to bolls or boll set, was 52% in both the 7 dhs and 14 dhs compared to 82% in the control. Although compensatory flowering allowed the 7 dhs and 14 dhs plants to produce more flowers than the control group, the lower conversion rate to bolls or boll set decreased the overall yield. The weight of the bolls and seeds and number of seeds per boll decreased with increased length of heat stress. Additionally, the longer the heat stress period, the higher the percent of malformed or sterile seeds. In conclusion, heat stress in excess of 25 C (77 F) negatively affects flax yield components.

The unique composition of flaxseed oil with a high percentage of ALA creates unique characteristics that can also be affected by the environment. Dybing and Zimmerman, (1965) concluded that during constant nighttime temperatures of 20 C (68 F) and varying day time temperatures of 15 C (59 F) to 30 C (86 F) at flowering, ALA percentage of the fatty acid profile decreased from 47% to 33.5% with the higher day-time temperatures. In addition, absolute oil yield and the iodine number were lowest in the highest daytime temperature treatments. Another study concluded that oil content and iodine number of flaxseed were reduced due to high temperatures during flax flowering

(Dillman and Hopper, 1943). Iodine number is calculated as the amount of unsaturated fatty acids in the oil composition (CGC, 2006).

Growth chamber studies, conducted in 1964 in Canada, showed that flax grown under cooler temperatures (18 C, 64 F) and increased photoperiod (19 hours) had higher total oil content, iodine value, and ALA. Flax grown under short photoperiods resulted in delayed flowering and reduction in both oil and ALA content (Sosulski and Gore, 1964). Carder (1957) has shown that daylength influenced different responses from flax grown at two different latitudes. Dillman and Hopper (1943) and McGregor and Carson (1961) concluded that flax cultivars originating from northern areas but grown in locations further south resulted in lower percent oil and a lower iodine number compared to being grown in a northern climate. This difference in flax response at different latitudes could be due to increased temperatures at southern latitudes during flowering and seed fill. Not only do climate conditions vary at different latitudes, but also throughout the planting season at individual locations.

This body of research concludes that exposure to temperatures in excess of 25 C (77 F) for extended periods of time during flax growth and development, specifically the reproductive stage, may negatively affect the grain and straw yield, and the percent oil quantity and oil quality characteristics of the seed. Because high temperatures during the summer for the Iowa and southern Minnesota region can reach over 26 C (80 F) for several days, the potential for unfavorable growing conditions exist. An early planting date was shown in the UK to be a strategy to avoid warm summer temperatures during reproductive development, thereby improving the quality of the flaxseed. Increased knowledge of the influence of regional environmental conditions on flax production will decrease future on-farm losses and determine the viability of this crop in upper Midwestern farming systems.

Cultivar evaluation

Different cultivars can reach physiological maturity at different times during the growing season. Because of this they are rated by a designated maturity rating which is the measurement of plant growth and development relative to a well established check utilizing standard linear regression analysis (Puskaric and Carrigan, 1988). Site specific effects from abiotic and biotic factors also influence the time to maturity. Examples of abiotic factors are temperature, available moisture, hours of sunlight and soil conditions. Biotic factors such as disease, pest damage and weed competition influence the time to maturity of a plant and its overall growth and development. Due to the potential for high temperatures during the summer months in the upper Midwest, fast maturing cultivars could escape potentially negative summer conditions. Although other yield trials measure oil content and sometimes the fatty acid profile, little analysis of the effect of biotic factors on these parameters has been cited.

Besides maturity ratings, two different groups of cultivars have been selected over time resulting in either yellow or brown-seeded flax. Some differences exist between these aesthetically different flax cultivars. A study conducted in Saskatoon in 1998 through 2002, compared seed weight and oil content of 2,730 brown-seeded accessions and 126 yellow-seeded accessions. From the five year study, weight of brown-seeded cultivars ranged from 2.83 - 11.50 mg ($9.9x10^{-5}$ - $4.1x10^{-5}$ oz) averaging 5.92 mg ($2.1x10^{-4}$ oz) per seed while yellow-seeded cultivars ranged 4.27 - 9.93 mg ($1.5x10^{-4}$ - $3.5x10^{-4}$ oz) averaging 6.31 mg ($2.2x10^{-4}$ oz) per seed. Oil content of brown-seeded cultivars ranged 31.4 - 45.7% averaging 38.3%; while yellow-seeded cultivars ranged 35.1 - 45.6% and averaged 39.4%. In both cultivar types, a heavier seed correlated with a higher percentage of total oil content. Yellow seeds typically were heavier than brown seeds and had a higher oil percentage. A higher oil content could be due to a thinner seed coat allowing for a higher concentration of oil (Diederichsen and Raney, 2006). Because the yellow seeds are heavier they are more likely to have larger plant organs that contain oil such as the cotyledons and the endosperms (Dorrell, 1970). Due to the inherent differences between cultivars, a study in Iowa of the readily available and appropriate accessions will provide farmers with knowledge of cultivar differences to make informed decisions for the production of organic flax.

Weed management strategies

Flax is not competitive with weeds because it produces little shade and uses water and soil nutrients less efficiently than most weed species (Gruenhagen and Nalewaja, 1969). Friesen (1986) stated that yield reductions caused by weeds would occur if flax producers were to eliminate herbicide use. Two different studies conducted in Manitoba, Canada concluded that yields of flax grain and straw were significantly decreased due to competition from weeds. From 1956 to 1958, the average reduction in flax grain yield was 27% due to the biomass of mixed weed populations. Compared to wheat, barley or oat yields, flax yield losses were consistently greater (Friesen and Shebeski, 1960). Likewise in a study in 1955, grain and straw yields were both reduced by as few as 11 plant m^{-2} (1 plant ft^{-2}) of wild mustard (*Brassica kaber* var. pinnatifida). Due to this competition from wild mustard , flax stands in weedy plots had low plant populations and the number of basal branches and bolls per plant was reduced (Burrows and Olson, 1955).

In Saskatchewan, Canada flax grain yield decreased by 20% when the density of cow cockle (*Saponaria vaccaria*) averaged 33 plant m^{-2} (3.1 plant ft^{-2}). Flax yields significantly decreased (73%) when weed population density reached 1,013 plant m^{-2} (95 plant ft^{-2}). In contrast to the previous study in Manitoba, which measured the effect of the weed species wild mustard, cow cockle did not decrease the flax stand and also had less damaging effects on flax yield (Alex, 1968). In North Dakota, flax grain yield decreased with competition from about 54 plant m^{-2} (5 plant ft^{-2}) of wild buckwheat (*Polygonum convolvulus* L.) (Gruenhagen and Nalewaja, 1966).

These studies show that weed competition during flax growth can reduce grain and straw yield and possibly decrease flax stands. To manage weeds in flax, pre and post-emergent herbicides are commonly used. Post-emergent broadleaf and grass herbicides are applied early when flax plants are 5 cm (2 in.) to 20 cm (8 in.) tall and weeds have germinated (Berglund and Zollinger, 2002).

In Manitoba, Canada a study comparing flax response to five seeding rates planted at two different depths and with and without a pre-emergent dinitroanaline herbicide application revealed that in a two-year study greater precipitation in 1993 resulted in a greater herbicide effectiveness. In 1992, flax yield increased in the seeding rate treatment 15 and 30 kg ha^{-1} (13.6 and 27.3 lb A^{-1}) as compared to only slightly in 30 to 90 kg ha^{-1} (27.3 to 81.8 lb A^{-1}) seeding rate treatment. No significant herbicide effect was illustrated. In 1993, the interaction of seeding rate and herbicide was significant. In the herbicide treated plots, seeding rate had no effect on flax yield, while in the untreated plots flax yields decreased as seeding rate increased. Flax populations were higher in the untreated plots resulting in greater disease incidence and lodging. Of the combined treatments means, shallow seeding (3 cm, 1.2 in.) increased flax populations. At both seeding depth, 3 cm (1.2 in.) and 6 cm (2.4 in.), higher seeding rate increased flax population density (Wall, 1994). Unfortunately, weed biomass weights were not reported for any of the treatments. Under dry conditions, herbicide effect may not provide sufficient weed control as compared to other cultural practices.

A study conducted in Saskatchewan, Canada compared four levels of post-emergence weed control: no control, broadleaf control, grass control and broadleaf + grass control concomitantly with three seeding rates of flax. Control of broadleaf and grass weeds resulted in the highest grain yield. In addition, for every 100 seed m^{-2} (1075 seed ft^{-2}) increase in flax seeding rate, broadleaf and grass weed yields decreased by 50 kg ha^{-1} (44.5 lb A^{-1}) and 23 kg ha^{-1} (20.5 lb A^{-1}), respectively. In all four levels of weed control, flax grain yield increased with higher flax seeding rate (Stevenson and Wright, 1996).

For farmers who practice organic methods or who want to decrease their use of chemicals, alternatives to herbicides are a must. Viable weed management strategies for flax production are important due to the potential long-term effects of weeds on these reduced chemical systems. Albrecht and Sommer (1998) measured an average increase from 4050 to 17320 weed seed m^{-2} (377 to 1611 ft^{-2}) in the soil seed bank three years after conversion from a conventional to an organic production system in the UK. The performance of future crops planted on flax fields could be affected if weeds are not managed during the year flax is planted in the farming rotation.

To combat weeds during the flax year without applying herbicides, producers can use cultural practices such as delayed planting with pre-seeding tillage to control early germinating weeds (Berglund and Zollinger, 2002); however, delayed planting may decrease flax grain yield (Dixit et al., 1994; Fontana et al., 1996; Shahidullah et al., 1997). Other strategies include varying crop rotation and tillage methods (Sarvis and Thysell, 1936; Puhr, 1962; Krall et al., 1965); decreasing row spacing (Klages, 1932; Dillman and Brinsmade, 1938; Alessi and Power, 1970); varying seeding rate (Albrechtsen and Dybing, 1973; Gubbels, 1978); varying seeding rate and row spacing (Hassan et al., 2005); intercropping flax with a legume (Klebesadel and Smith, 1959) and varying rates of nutrient application (Culbertson et al., 1961).

These studies using various cultural practices to control weeds during the flax year to compared the resulting flax grain yields with weed biomass production or weed stand counts. The majority of these studies do not describe how weeds were managed. One study did compare hand-weeded and weedy plots (Alessi and Power, 1970). If a herbicide was applied to control weeds in any of these studies, then an accurate evaluation of the cultural treatment’s performance was not assessed. Ideally, splitting the experimental plots and hand-weeding half the plot accurately assesses the performance of the weed management strategy.

Alternative crop production

Over-production of commodity crops has devastated our landscape both environmentally and socially (Comstock, 1987; Goldschmidt, 1998; Thompson, 1995). Human and environmental health has been affected by the increased use of chemicals in the form of pesticides to control various pests of the production system. Herbicides such as Atrazine have been studied and results prove that it persists in our water and is a known endocrine disruptor (NRDC, 2004). Socially, modern agriculture has reduced the number of farmers drastically through concentration of the industry into the hands of fewer producers who possess larger amounts of financial and built capital than their smaller scaled neighbors (NASS, 2007). However even with increased research of specific crops, increased use of technology and improved efficiencies, the current production system has not reduced the numbers of hungry and food insecure people in the rural and urban United States as well as around the world (Lappé et al., 1998).

In reaction to this industrial form of agriculture, farmers have begun alternative farming and marketing systems. Alternative farming techniques that incorporate civic values outside the industrial convention are reflected in the increased number of organic acres and the presence of grass-fed, natural and hormone-free products in the grocery store (Fitzgerald, 2005; Greene, 2006). However, this transition to alternative agriculture production has come about slowly due to the considerable new human, social, cultural, political, financial, built and environmental capital needed to change the ability in which farmers currently can practice agriculture. To distinguish between farmers' intentions and agency to employ alternative agriculture practices, this study describes four farmer participants in the context of conventions theory and documents what capitals they used to decide to grow a new crop.

Conventions theory initially described by Boltansky and Thevenot (1991) forces a predominantly economic model to be evaluated by new characteristics beyond price. The quality of a product in a market is characterized beyond its monetary value (Sylvander, 1994). In Renard (2003), four conventions: industrial, market, civic, and domestic, are described. These four conventions were used to categorize a group of four farmer cooperators who conducted on-farm research with an alternative crop flax in 2005.

Trust, respect, partnership, attachment to place and tradition are characteristics of a *domestic* convention. A *civic* convention values the benefits to the greater society. It is based on an idea of collective responsibility, fairness and equality. A civic convention's inference is greater than a domestic convention but both have similar objectives: societal benefits. A *market* convention is characterized by its dependence on commercial prices, organizations that buy and sell products and retailers and distributors that bring the product to market. The characteristic of the product is minimized to its profit in the market place. The civic and domestic conventions still function within a market convention but with additional characteristics of the product being traded. For example, by whom, how and where was the product was produced is important. An *industrial* convention depends on formal standards, inspections and certifications of products, efficiency and the reliability of standardization. The industrial convention favors products that adhere to the market convention with an increased focus on its suitability for processing, use by industry buyers and ability to be reduced to individual parts for use by processors and sold by retailers.

The Community Capitals Framework was chosen to attain reactions to specific questions categorized by the seven capitals: human, social, cultural, environmental, built and financial described by Flora (2004). This tool is currently used to assess strategic interventions and projects by the North Central Regional Center for Rural Development (NCRCRD), which initiates research and outreach projects in the rural communities of the north central United States in collaboration with other regional rural development centers (NCRCRD, 2006).

Each capital represents a specific piece of the interaction between a person, the surrounding community and the context within which they both exist. *Human* capital is comprised of the skill sets, knowledge and capacities that people possess or attain. *Social* capital is the interaction between citizens and community support organizations, such as non-profits, government agents, industry, educators, lenders and business leaders. Built capital and financial capital were separated into two categories although they are very similar. *Built* capital is the tangible, physical infrastructure and facilities that exist for citizens or communities to increase access to and trade of goods and services. *Financial* capital is considered credit, income, wages or earnings from the sale of on-farm products such as grain or animals. *Environmental* capital is also referred to as natural capital and is described as the diversity and stability of the environment which exist on farms or the potential for increased ecosystem diversity and stability. *Cultural* capital is embedded in the values and practices of the farmers and rural inhabitants. *Political* capital is the ability for farmers to have a platform where they can advocate and be recognized. This indicator is distinct from social and cultural capital in that it goes beyond the local community and identifies access to elected officials such as state or federal policy makers or government officials. The capitals framework was employed to analyze and compare each farmer's specific situation. Their responses were categorized by the capital and used to assess how and why these producers carved out a physical and temporal space to produce an alternative crop (NCRCRD, 2006).

The objectives of this research are a biological and sociological approach. These results will provide upper Midwestern, specifically Iowa, organic farmers with current, agronomic production guidelines from research conducted on-farm and on experiment stations, and to analyze the capability of these farmers to incorporate this alternative crop into their crop rotations. The effect of planting date, cultivar selection, planting rate, legume establishment, weed management strategies categorized as mechanical, chemical and biological: flax grain yield, straw biomass yield, total oil content, fatty acid profile, and underseeding and weed biomass production are analyzed. Additionally, straw quality characteristics were assessed.

Literature cited

Albrecht, H., and H. Sommer. 1998. Development of the arable weed seed bank after the change from conventional to integrated and organic farming. Aspects of Applied Biology, Weed seedbanks: determination, dynamics and manipulation 51:279-288.

Albrechtsen, R.S., and C.D. Dybing. 1973. Influence of seeding rate upon seed and oil yield and their components in flax. Crop Sci. 13:277-280.

Alessi, J., and J.F. Power. 1970. Influence of row spacing, irrigation and weeds on dryland flax yield, quality, and water use. J Am Soc Agron. 62:635-637.

Alex, J. 1968. Competition between linseed flax and *Saponaria vaccaria*. Can J Plant Sci. 48:1968.

Berglund, D., and R. Zollinger. 2002. Flax production in North Dakota. Extension Publication A-1038. North Dakota State University Extension.

Berry, J.A, and O. Bjorkman. 1980. Photosynthetic response and adaption to temperature in higher plants. Annu Rev Plant Phy. 31:491-543.

Boltansky, L., and L. Thévenot. 1991. De la justification. Les economies de la grandeur. Nrf essais, Gallimard.

Burrows, V., and P. Olson. 1955. Reaction of small grains to various densities of wild mustard and the results obtained after their removal with 2,4-D or by hand. II Experiments with flax. Can J of Agr Sci. 35:193-201.

Canadian Grain Commission (CGC). Western Canadian flaxseed 2006: iodine value. Accessed online on 11/16/2007 at http://grainscanada.gc.ca/quality/flax/2006/iv/flaxhs06-e.htm.

Carder, A. 1957. Growth and development of some field crops as influenced by climatic phenomena at two diverse latitudes. Can J Plant Sci. 37:392-406.

Comstock, G. 1987. Is there a moral obligation to save the family farm? Iowa State University Press.

Cross, R., S. McKay, A. G. McHughen, and P. Bonham-Smith. 2003. Heat-stress effects on reproduction and seed set in *Linum usitatissimum* L.(flax). Plant Cell and Environment 26:1013-1020.

Culbertson, J.O., H.W. Johnson, and L.G. Schoenleber, (eds.) 1961. Producing and harvesting seeds of oilseed crops. U.S. Gov't Print Off. 591:1-192-199.

Diederichsen, A., and J. Raney. 2006. Seed colour, seed weight and seed oil content in *Linum usitatissimum* accessions held by Plant Gene Resources of Canada. Plant Breeding 125:372-377.

Dillman, A., and T. Hopper. 1943. Effect of climate on the yield and oil content of flaxseed and on the iodine number of linseed oil. USDA Tech Bull:1943.

Dillman, A.C., and J.C.J. Brinsmade. 1938. Effect of spacing on the development of the flax plant. J Am Soc Agron. 30:267-278.

Dixit, J.P., S.K. Chourasia, P.V.A. Pillai, and R.A. Khan. 1994. Assessment of flexibility of sowing time of linseed (*Linum usitatissimum)* varieties under double cropping system in Tawa Command. Indian J Agron. 39:105-109.

Dorrell, D. 1970. Distribution of fatty acids within the seed of flax. Can J Plant Sci. 50:71-75.

Dybing, C., and D. Zimmerman. 1965. Temperature effects on flax (*Linum usitatissimum* L.) growth, seed production, and oil quality in controlled environments. Crop Sci. 5:184-187.

Fitzgerald, A. 2005. Organic's popularity outpaces production: There's room for meat, dairy and grain farmers to convert, but barriers slow growth. Des Moines Register.

Flora, Cornelia. 2004. Rural communities: legacy and change. Boulder Westview Press, 2004.

Fontana, F., D. Cremaschi, C. Vender, C. Maestrini, and L. Natarelli. 1996. Comparison of two spring sowing dates for linseed (*Linum usitatissimum* L.) cultivars. Rivista di Agronomia 30:248-251,896.

Ford, J., and D. Zimmerman. 1964. Influence of time of flowering on oil content and oil quality of flaxseed. Crop Sci. 4:653-656.

Friesen, G., and L. Shebeski. 1960. Economic losses caused by weed competition in Manitoba grain fields. I. Weed species, their relative abundance and their effect on crop yields. Can J Plant Sci. 40:457-467.

Friesen, G.H. 1986. Effect of weed interference on yield and quality of flax seed oil. Can J Plant Sci. 66:1037-1040.

Gardner, F., and W. Loomis. 1953. Floral induction and development in ochardgrass 1. Plant Phy. 28:201-217.

Greene, C. 2006. Organic Production 1999-2003. Economic Research Service. Accessed online on 04/20/2008 at http://www.ers.usda.gov/Data/Organic/

Goldschmidt, W. 1998. Conclusion: The urbanization of rural America. Pigs, profits, and rural communities:183–198.

Gruenhagen, R., and J. Nalewaja. 1966. Wild buckwheat competition in flax. Meet Weed Soc Amer. 56.

Gruenhagen, R.D., and J.D. Nalewaja. 1969. Competition between flax and wild buckwheat. Weed Science 17:380-384.

Gubbels, G.H. 1978. Interaction of cultivar and seeding rate on various agronomic characteristics of flax. Can J Plant Sci. 58:303-309.

Gusta, L., B. O'Connor, and R. Bhatty. 1997. Flax (*Linum usitatissimum* L.) responses to chilling and heat stress on flowering and seed yield. Can J Plant Sci. 77:97-99.

Hassan, F., M. Leitch, and M. Abbasi. 2005. Effects of seeding densities and row spacing on yield and yield components of linseed (*Linum usitatissimum* L.). Acta Agronomica Hungarica 53:309-317.

Herrero, M., and R. Johnson. 1980. High temperature stress and pollen viability of maize. Crop Sci. 20:796-800.

Hong, S., and E. Vierling. 2001. Hsp 101 is necessary for heat tolerance but dispensable for development and germination in the absence of stress. The Plant Journal 27:25-35.

Hopper, T., and L. Nesbitt. 1935. Flax investigations. Bulletin 286. North Dakota Experiment Station Bulletin 286.

Klages, K.H. 1932. Spacing in relation to the development of the flax plant. J Am Soc Agron. 24:1-17.

Klebesadel, L., and D. Smith. 1959. Light and soil moisture beneath several companion crops as related to the establishment of alfalfa and red clover. Botanical Gazette 121:39-46.

Kraft, J., T. Kommedahl, and A. Linck. 1963. Histological study of malformation in flax seed after exposure to 31 C. Botanical Gazette 124:367-371.

Krall, J.L., T.J. Army, A.H. Post, and A.E. Seamans. 1965. A summary of dryland rotations and tillage experiments at Havre, Huntley and Moccasin, Montana. 599. Montana Agr Expt Sta Bull.

Lappé, Frances Moore, Joseph Collins, Peter Roseet, Luis Esparza., 1998 World hunger: twelve myths. 2nd Edition New York: Grove Press.

Lindsey, K., and M. Peterson. 1964. Floral induction and Varshney, JG, 1995. Response of dwarf pea cultivars to dates of development in *Poa pratensis*. Crop Sci. 4:540-544.

McGregor, D.I., and R.B. Carson. 1961. Fatty acid composition of flax varieties. Can J Plant Sci. 41:816.

National Agriculture Statistics Service (NASS). 2007. U.S. & All States Data - Farm Numbers - Total Farms, Land in Farms, Average Farm Size. Accessed online on 11/16/2007 at http://www.nass.usda.gov/Statistics_by_Subject/Demographics/index.asp.

Natural Resources Defense Council (NRDC). EPA Won't Restrict Toxic Herbicide Atrazine, Despite Health Threat: White House documents obtained by NRDC reveal that industry influenced the decision. Accessed online on 11/16/2007 at http://www.nrdc.org/health/pesticides/natrazine.asp.

North Central Regional Center for Rural Development (NCRCRD). 2006. Community capitals handout. Accessed online on 11/16/2007 at http://www.ncrcrd.iastate.edu/projects/commcap/7-capitalshandout.pdf.

Oplinger, E.S., E.A. Oelke, J.D. Doll, L.G. Bundy, R.T. Schuler. 1997. Flax. alternative field crops manual. Accessed online on 11/16/2007 at http://www.hort.purdue.edu/newcrop/afcm/flax.html.

Painter, E., L. Nesbitt, and T. Stoa. 1944. The influence of seasonal conditions on oil formation and changes in the iodine number during growth of flaxseed. J of Am Soc of Agron. 36:204-213.

Peet, M., S. Sato, and R. Gardner. 1998. Comparing heat stress effects on male-fertile and male-sterile tomatoes. Plant Cell and Environment 21:225-231.

Peterson, M., and W. Loomis. 1949. Effects of photoperiod and temperature on growth and flowering of kentucky bluegrass. Plant Phy. 24:31-43.

Puhr, L.F. 1962. Twenty years of soil management on a vienna silt loam. 508. South Dakota Agr Expt Sta Bull.

Puskaric, V., and L. Carrigan. 1988. Hybrid corn plant and seed. Google Patents.

Renard, Marie-Christine. 2003. Fair trade: quality, market and conventions. Journal of Rural Studies. 19:87-96.

Sarvis, J.T., and J.C. Thysell. 1936. Crop rotation and tillage experiments at the Northern Great Plains Field Station 536. North Dakota USDA Tech Bull., Manden, ND.

Shahidullah, M., U. Islam, M. Karim, and R. Mondol. 1997. Performance of four linseed varieties: at different dates of sowing. J Scientific and Industrial Res. 32:186-190.

Siddique, A., D. Wright, S. Ali, and A. Mollah. 2002. Effects of sowing dates on the phenology, seed yield and yield components of flax. Online Journal of Biological Sciences 2:366-369.

Sosulski, F.W., and R.F. Gore. 1964. The effect of photoperiod and temperature on the characteristics of flaxseed oil. Can J Plant Sci. 44:381-382.

Stevenson, F., and A. Wright. 1996. Seeding rate and row spacing affect flax yields and weed interference. Can J Plant Sci. 76:537-544.

Sylvander, B. 1994. La qualité: du consommateur final au producteur (la construction sociale de la qualité: des produits aux facons de produire). Etudes, Recherches en Systèmes Agraires et Développement, INRA. 28: 27-49.

Thompson, P. 1995. The spirit of the soil. Routledge London.

USGS. 2006. Northern Prairie Wildlife Research Center. Climate of North Dakota. Accessed on 11/16/2007 at http://www.npwrc.usgs.gov/resource/habitat/climate/temp.htm.

Wall, D.A. 1994. Response of flax and lentil to seeding rates, depths and spring application of dinitroanaline herbicides. Can J Plant Sci. 74:875-882.

CHAPTER III

Planting date and flax cultivar evaluation in Iowa

Introduction

Production of flaxseed has increased in Iowa due to a rise in human consumption and with the recent construction of a certified organic oilseed expelling facility in northwestern Iowa. Consumption of this seed has shifted from primarily industrial uses as paint and livestock cakes during WWII to human uses as nutra-ceuticals (Green and Marshall, 1981). Human consumption has increased with the recent documentation of the importance of omega-3 fatty acids in human diets (Connor, 2000). Omega-III is the common name for alpha linolenic acid (ALA). It is an essential fatty acid that cannot be manufactured by the body and therefore needs to be obtained by food. Flax is well known for its unique fatty acid profile, specifically, the high content of ALA, which typically ranges between 45% and 65% of the total oil of the seed (Vrinten et al., 2005).

Flax is traditionally grown in Canada and North Dakota where soil conditions are favorable and few other competing crops exist. Flax yield components are negatively affected by temperatures in access of 25 C (77F). Grain yield was reduced with increased temperatures (Dillman and Hopper, 1943; Dybing and Zimmerman, 1965; Painter et al., 1944; Kraft et al., 1963; Ford and Zimmerman, 1964; Gusta et al., 1997; Cross et al., 2003;) and also oil quantity and quality responded negatively with warmer temperatures (Dybing and Zimmerman, 1965; Dillman and Hopper, 1943; Sosulski and Gore, 1964; McGregor and Carson, 1961).

These studies suggest that high temperatures, which occur in increased frequency later in the growing season, reduced flax grain yield and oil quantity and quality. In Iowa, growing season temperatures can reach into the 37.7 C (100 F) for several days. This combination and the potential negative impact on grain yield and oil characteristics might be significant enough to deter farmers from growing this alternative crop.

Finally, different cultivars can reach physiological maturity at different times during the growing season. Selecting fast maturing cultivars could decrease the negative impact of high temperatures later in the growing season. Due to the inherent differences between cultivars, a study of the readily available and appropriate accessions for Iowa will provide farmers with knowledge of cultivar differences to make informed decisions for the production of flax.

Objectives of this research address researchers’ and farmers’ need to know how planting date and cultivar selection will affect flax grain yield, straw biomass yield, total oil content, ALA percentage of the oil and the fatty acid profile. Our hypotheses are: 1) measured parameters will be higher for early planting date compared to a later planting date, 2) measured parameters will be greater in faster maturing cultivars as compared to later maturing cultivars.

Materials and methods

Description of locations

The experiment was conducted in 2005 and 2006 at two locations in Iowa: at the ISU Agronomy and Ag Engineering Research Farm near Boone, IA (Central IA) (42.0^{o} N, 93.0^{o} W, elevation 354 m, (1161 ft)), on a Webster-Nicolet, fine-loamy, mixed, superactive, mesic, Typic Engoquoll soil and at the ISU Northwest Research and Demonstration Farm near Sutherland, IA (NW IA) (42.9^{o} N, 95.5^{o} W, elevation 445 m, (1460 ft)), on a Primghar silty clay loam, fine-silty, mixed, mesic Aquic Hapludolls soil. Soil test results at Central IA indicated a soil pH of 7.3 (2005) and 7.4 (2006), phosphorus (Bray P_1) levels of 11 ppm (2005) and 12 ppm (2006), potassium levels of 93 ppm (2005) and 109 ppm (2006) and an organic matter content of 5.6% (2005) and 5.2% (2006). At NW IA, the soil test results indicated a soil pH of 5.9, phosphorus (Bray P_1) level of 21 ppm, potassium level of 152 ppm and organic matter content of 3.8% for both years.

Seedbed preparation

The specific soil conditions in each year at each location determined the primary and secondary tillage used in the spring. At Central IA, in 2005 and 2006, the field was tandem disked followed by application and immediate incorporation with a field cultivator of 66 kg N ha^{-1} (59 lb N A^{-1}) as urea. Plots were cultivated prior to each planting date. Additionally in 2005, 59 kg (130.4 lb) of phosphate fertilizer product (0-46-0) was applied. At NW IA, in 2005 and 2006, experimental areas were initially disked. Each year, 59.4 kg N ha^{-1} (53 lb N A^{-1}) was applied as urea. Plots were field cultivated prior to each planting date.

Treatments

All treatment combinations were replicated four times in a randomized complete block design with planting date as the main plot and cultivar as the subplot. All plots were 2.1 m x 7.6 m (7 ft x 25 ft). The early flax planting date (PD) was based on the local planting dates for small grain crops. Two planting date treatments were intended to occur 10 and 20 days following planting date one (Table 1). In Central IA and NW IA, the majority of small grains were planted before 10 April in 2005 and 23 April in 2006 (M. Smith, personal comm., 2006). Five flax cultivars, selected to represent a range of maturity and listed in order of maturity rating from early to late, were ‘Norlin,’ ‘Hanley,’ ‘Carter,’ ‘Bethune’ and ‘York’ (Ransom and Berglund, 2006). All seed used in the study except Hanley was germination tested using the AOSA standards for testing flax seed and certified for 2005. Hanley was certified for 2004. In 2006, seed was certified except Bethune and Norlin which had resulting germination tests of 94% and 92%.

At Central IA, flax was drilled with a 2.1 m (7 ft) wide Tye no-till drill with 0.179 m (7 in.) row spacing at a rate of 56 kg ha^{-1} (50 lb A^{-1}). At NW IA, flax was drilled with a 2.4 m (8 ft) wide Massey Ferguson wide end-wheel drill with single disk openers and 0.178 m (7 in.) row spacing at a rate of 56 kg ha^{-1} (50 lb A^{-1}). In 2005 at Central IA, flax was underseeded with 15.7 kg ha^{-1} (14 lb A^{-1}) of red clover (*Trifolium pratense* L. ‘medium’) at flax planting. For organic farming systems in this region, red clover is typically used as a biological weed control strategy and as nitrogen fertility for the subsequent growing season. In NW IA, no underseeding was planted.

On 24 May 2005 an application of MCPA broadleaf herbicide was applied at a rate of 0.58 liters ha^{-1} (0.06 gal A^{-1}) to the first planting date plots, but not to the two later planting dates. In 2006, both sites were underseeded with red clover at a rate of 15.7 kg ha^{-1} (14 lb A^{-1}) at flax planting. In 2006 at Central IA, the grass seeder tubes on the Tye no-till drill were offset from the main hopper box to allow the red clover seed to fall between the flax rows as opposed to directly into the flax row. Flax experiments were planted on land previously seeded to soybeans, using chemical herbicides to manage weeds. A minimum amount of soybean residue was observed.

Monthly averages of the precipitation and temperature values were measured for each site (Tables 2 and 3). Temperature values for each individual growing season were recorded (Table 4). Temperature for each growing season increased with a delayed planting date.

Data collection

Flax was harvested when experimental plots were physiologically mature, defined as showing 90% dark brown bolls (Berglund and Zollinger, 2002). At Central IA, Norlin, Bethune and Hanley cultivars from PD 1 were harvested on 13 July 2005 and all other treatments were harvested on 27 July 2005. In 2006, Hanley and Norlin cultivars from PD 1 were harvested on 14 July 2006 and all other treatments were harvested on 18 July 2006. At NW IA, PD 1 treatments were harvested on 28 July 2005; PD 2 and PD 3 treatments were harvested on 9 August 2005. In 2006, Norlin from PD 1 was harvested on 20 July 2006 and all other treatments were harvested on 8 August 2006.

Four quadrates (1 ft^2) were randomly placed on the ground encompassing two rows and two interrows of planted flax. Pruning shears were used to cut flax plants at the height of the quadrant 0.0245 m (1 in.). Immediately after harvest, weeds and red clover biomass were separated from flax plants. In 2005, the weed and red clover fractions were discarded; but in 2006, all material was collected and separated into fractions of red clover, flax, and grass and broadleaf weed species. Flax plants were placed into cloth bags and dried at ambient air temperature for three days. All other fractions were placed in paper bags and dried at 60 C (140 F) for seven days. Red clover and weed biomass was then weighed to determine total dry matter (DM) yield of each fraction. After air drying the flax was threshed. In 2005, threshing was by hand; in 2006, it was machine threshed using an Almaco small bundle thresher. Quadrates from each plot were combined and flaxseed was cleaned using a South Dakota seed cleaner in 2005 and a Westrup LA-LS laboratory air-screen cleaner in 2006. Grain moisture was measured using ISO standard procedures for flax grain moisture. One gram of flaxseed was baked at 103 C (217.4 F) for three hours to measure the moisture content (V. Barthet, personal comm., 2006). Grain yield was adjusted for moisture content.

The total oil percentage of flaxseed was measured using a Newport 4000 Nuclear Magnetic Resonance Analyzer from Oxford Analytical Instruments Limited. A 40 ml (1.4 oz) sample was used to non-destructively measure the percentage oil of the seed.

Gas chromatography (GC) was used to determine the fatty acid profile of the oil content. Fatty acid composition is expressed as the percent by weight of the C16 to C24 saturated fatty acids divided by the weight of all fatty acids (Vick et al., 2004). A whole or half flaxseed was placed in a GC autosampler vial and crushed with a thin (end-flattened) glass rod. A 1.0 – 1.5 ml (0.03 – 0.05 oz) of a hexane-chloroform-0.5 M sodium methoxide in methanol (75:20:5, v/v) solution was added to the vial. The sample was injected into a Hewlett-Packard 589-gas chromatograph containing a DB-23 capillary column (30 m x 0.25 mm, J&W Scientific), which was held at 190 C (374 F) for five minutes, then increased to 220 C (428 F) at 10 C minute^{-1} (50 F minute^{-1}). The sample was held at 220 C (428 F) for one minute, then increased to 240 C (464 F) at 20 C minute^{-1} (68 F minute^{-1}), and finally held at 240 C (464 F) for one and a half minutes. The total run time was 11.5 minutes.

After threshing, the straw was dried at 60 C (140 F) for five days and weighed.

Statistical analysis

Statistical analysis was performed using the least square means for the MIXED model procedure of the Statistical Analysis System (SAS). Regression analysis was conducted of each parameter. If the interaction in the MIXED model was significant, individual regression analysis was conducted by year and project. To analyze the four way interaction, planting date for each site-year was qualified as 1, 2, or 3. If the four-way interaction was significant in PROC MIXED, growing degree days were used to assess the affect of planting date on each parameter and run regression analysis. Growing degree days were calculated from the daily heat accumulated between 1 January and until the actual planting date. The daily heat accumulated was calculated using base temperature 0 C (32 F) and no high temperature. The equation used was $GDD=(T_{max} + T_{min})/2 – T_{base}$. Tests of differences among lsmeans were made at the 0.05 probability level and different treatment means were compared using pdiffs.

Results and discussion

Grain yield

The interaction of year, location, planting date and cultivar was significant with a p-value of 0.0001 for grain yield. In 2005, the interaction of planting date and cultivar was significant at both NW IA (p>0.0443) and Central IA (p>0.0249). Flax grain yield decreased significantly in all cultivars with a later planting date at both sites (Figs. 1 and 2). At NW IA in 2005, the slopes of the cultivars were all significantly different from zero. At Central IA in 2005, all slopes of the cultivars were significantly different from zero except Bethune which had a p-value of 0.0143. A slope significantly different from zero indicates that the treatment affected the measured parameter either positively or negatively depending on the direction of the slope.

In 2006, at both sites the interaction between planting date and cultivar was not significant. At both sites in 2006, flax grain yield was negatively affected by planting date with p-values 0.0336 in NW IA and 0.0033 in Central IA (Fig. 3). Grain yield ranged from 1506.35 to 1270.47 lb A^{-1} at NW IA and in Central IA from 1069.87 to 157.88 lb A^{-1}. Hanley yielded significantly lower grain yield (1219.15 lb A^{-1}) than the other four cultivars in 2006 at NW IA (average yield 1361.36 lb A^{-1}) (Fig. 4).

A negative response to a delayed planting date was expected. From a review of the literature several studies have shown that a delayed planting date affects flax yield components (Siddique et al., 2002a; Siddique et al., 2002b; Dixit et al., 1994; Fontana et al., 1996; Shahidullah et al., 1997). Additionally, cultivars were selected based on a maturity rating to assess whether an early maturing cultivar could ripen fast enough to escape high, mid-summer temperatures. A difference among cultivars was expected but analysis by maturity rating was not conducted.

Straw yield

The interaction of all factors: year, location, planting date and cultivar, was significant with a p-value of 0.0001. Planting date negatively affected straw yield at both sites in 2005 (Fig. 5). Neither planting date nor cultivar influenced flax straw yield in 2006 at NW IA but at Central IA cultivars were different (Fig. 6). Norlin yielded 1269.69 lb A^{-1}, a significantly lower amount of straw than the other four varieties. Bethune yielded 1868.97 lb A^{-1}, Hanley yielded 1779.02 lb A^{-1}, Carter yielded 1653.09 lb A^{-1} and York yielded 1605.12 lb A^{-1}.

Few studies have been conducted that discuss planting date effect or cultivar differences effect on straw yield. Height of plants was measured (data not shown) but no obvious correlation between height and resulting straw yield was present. Height of flax averaged 20.5 in.

Oil

A delayed planting date did not affect the total oil content of the flax grain. Total oil content was only different among cultivars at NW IA in 2006 (Fig. 7). Bethune yielded the greatest oil content at 44.75%. Carter yielded 43.46%, Hanley yielded 41.53%, Norlin yielded 41.76% and York yielded 42.73%. Dillman and Hopper (1943), McGregor and Carson (1961), Sosulski and Gore (1964) showed that under warmer temperatures total oil content of flaxseed decreased. The results from this study at two sites in Iowa over two years do not support the above mentioned authors' results. Difference in total oil content among cultivars was expected due to different phenotypes expressed during the breeding process; however, lack of a PD effect was not expected.

The oil content of the flax did meet the contract requirements of a flax grain buyer in Iowa. However this buyer currently only purchases two cultivars, Bethune and Norlin. This study suggests that Bethune and Norlin benefit the buyer more than the farmer because of the high oil content in the seed. More oil is available for pressing while buying less grain. But these cultivars, Bethune and Norlin, did not consistently have high grain yields as compared to York and Hanley. In 2005 at both sites and Central IA in 2006, York and Hanley yielded the highest grain yields among the cultivars. A larger cultivar evaluation is needed to benefit both farmers and industry with high yielding flaxseed with high oil content.

Fatty acid profile

The interaction of all factors: year, location, planting date and cultivar, was significant with a p-value of 0.0001 for ALA (18:3) percentage of the oil. Alpha linolenic acid was negatively affected in three of the four site-years (NW IA 05, Central IA 06

(Fig. 8) and NW IA 06 (Fig. 9). At NW IA in 2005 and Central IA in 2006 where cultivars responded the same to a delayed planting date, ALA values ranged from 51.1% to 44.7% and 53.2% to 47.1%, respectively (Fig. 8). At Central IA in 2005, ALA percentage of cultivars, Carter, Hanley and Norlin increased with a delayed planting date (Fig. 10). Bethune and York both increased from the early to mid-spring planting date (PD 1 to PD 2) and decreased from the mid-to late planting date (PD 2 to PD 3).

Alpha linolenic acid percentage varied significantly among the five cultivars in NW IA in 2005 and Central IA in 2006 (Fig. 11). At both sites, Carter and Hanley yielded significantly higher than the other cultivars. At NW IA in 2005, Carter and Hanley averaged 50.9% and 50.2%, respectively. At Central IA in 2006, Carter and Hanley averaged 52.1% and 52.7%, respectively.

The ALA percentage of the total oil content is not measured by the industry buyer in Iowa, although their contract stipulates an ALA% of 52%. If farmers needed to provide flax oilseed with the oil content yielding 52% ALA, these five cultivars grown at different planting dates and tested in different sites and years may not meet the contracted amount. After calculating the ALA percentage of the vender's nutrition label on a bottle of flaxseed oil, the oil is reported as containing 57% ALA, i.e. 0.28 oz (8 g) of ALA within 0.49 oz (14 g) fat. Another vender reports that their flaxseed oil contains 45% ALA (0.05 oz (1.365 g) out of 0.11oz (3 g) of fat or 0.23 oz (6.415 g) out of 0.49 oz (14 g) fat). If the ALA percentage of the oil content is measured in the future, Iowa farmers may not be able to meet this requirement and could be docked for low quality oil or have their grain rejected. New cultivars will need to be assessed to make sure farmers are growing a product that they can sell.

The interaction of all factors was significant with a p-value of 0.0001 for linoleic acid (18:2) percentage of the oil. The interaction of planting date and cultivar was significant in three of four site-years. At Central IA in 2005 all cultivars were negatively affected by a delayed planting date (Fig. 12). In NW IA in 2006, all cultivars were positively influenced (Fig. 13). All cultivars at Central IA in 2006, were negatively influenced except Norlin which increased with a delayed planting date (Fig. 14). In NW IA in 2005, planting date positively affected all the cultivars the same (Fig. 15). Hanley (16.4%) yielded the greatest linoleic acid percentage compared with the other cultivars (Fig. 16). No consistent planting date effect on linoleic acid percentage was shown. In two site-years the majority of cultivars were negatively affected while in the other two site-years a delayed planting date increased linoleic acid percentage. Of the cultivars, Norlin consistently yielded 1% less than the other cultivars.

The interaction of all factors was significant with a p-value of 0.0001 for oleic acid (18:1) percentage of the oil. In NW IA in 2005 and Central IA in 2006, oleic acid increased with a delayed planting date (Fig. 17). In Central IA 2005, Carter, Hanley and Norlin were negatively affected while Bethune and York increased with a delayed planting date (Fig. 18). In NW IA in 2006, all cultivars were positively affected by a delayed planting date. York was not significantly different from zero ($p>0.0262$) (Fig. 19).

Differences among cultivars existed in NW IA 2005 and Central IA in 2006 (Fig. 20). Bethune had the greatest oleic acid percentage in both site-years (29.78% and 26.38%) and was significantly higher than the other cultivars. In NW IA 2005, oleic acid yields of the other cultivars ranged from 22.18% to 29.71% and in Central IA 2006, from

20.01% and 25.92%. In all the treatments Hanley consistently yielded less than the other cultivars.

The interaction of all factors was significant with a p-value of 0.0001 for stearic acid (18:0) percentage of the oil. In NW IA in both years stearic acid percentage of the oil responded positively to a delayed planting date (Fig. 21). The interaction between planting date and cultivar was significant in Central IA in both years. At Central IA in 2005, all cultivars were negatively affected by planting date except Bethune, which increased (Fig. 22). In 2006, all cultivars responded positively (Fig. 23). No consistent planting date effect on stearic acid can be determined from these results.

In NW IA cultivars responded the same across planting dates. In both years, York and Bethune had the greatest stearic acid percentage, averaging 4.61% and 4.47%, respectively. Hanley had significantly less stearic acid averaging 3.15% (Fig. 24).

Palmitic acid (16:0) was different among cultivars but was not affected by planting date. Hanley yielded the highest palmitic acid, 6.29%. York and Norlin were similar yielding 5.87% and 5.69%. Carter yielded 5.68% and Bethune yielded 5.64%. Years and locations also affected the palmitic acid percentage. Palmitic acid percentage was 6.33% in 2006 and 5.33 in 2005. Central IA yielded slightly higher palmitic acid at 5.94% compared to NW IA with 5.72%.

Individual fatty acids (FA) were influenced differently by the effect of a delayed planting date. Average temperature of the growing season increased with a later planting date (Table 4). This is illustrated by an increase in growing degree days calculated from daily heat units accumulated from 1 January to the date of planting. In addition, the cultivars used in this study were bred in cooler, drier climates in North Dakota and

Canada. The above results do not consistently support other studies which have shown that more unsaturated fats, i.e. ALA, are present when flax is grown under cooler climate conditions.

Conclusions

In summary, a delayed planting date will negatively affect grain yield and sometimes the level of unsaturated fat in the seed due to warmer temperatures later in the growing season. During plant growth, photosynthetic tissue rapidly matures when exposed to warmer temperatures; resulting in shortened vegetative growth stages. This leads to less plant capacity to harvest sunlight for conversion to photosynthates necessary for growth and development. Although temperature has also been reported to cause a decrease in the level of unsaturated fatty acids, it is not the only factor. In non-photosynthetic tissue, such as seeds, the activity of the gene *FAD3*, which transcribes the desaturases responsible for elongation of C16-18 carbon chains is affected by the decrease in oxygen gas solubility at higher temperatures. Tissues that cannot create a constant supply of oxygen through photosynthesis, nor concentrate oxygen, have a decreased level of enzyme activity due to a limitation of oxygen. Therefore, planting flax as early as possible in the upper Midwest will help the plant avoid warm mid-summer temperatures that negatively impact its grain yield. Without these extreme summer temperatures the currently sought out quality characteristics of a highly unsaturated fatty acid profile will be more easily met for industry buyers.

Literature cited

Berglund, D., and R. Zollinger. 2002. Flax production in North Dakota. Extension Publication A-1038. North Dakota State University Extension.

Connor, W. 2000. Importance of n-3 fatty acids in health and disease. American Journal of Clinical Nutrition 71:171S-175S.

Cross, R., S. McKay, A. G McHughen, and P. Bonham-Smith. 2003. Heat-stress effects on reproduction and seed set in *Linum usitatissimum* L.(flax). Plant Cell and Environment 26:1013-1020.

Dillman, A., and T. Hopper. 1943. Effect of climate on the yield and oil content of flaxseed and on the iodine number of linseed oil. USDA Tech Bull:1943.

Dixit, J.P., S.K. Chourasia, P.V.A. Pillai, and R.A. Khan. 1994. Assessment of flexibility of sowing time of linseed (*Linum usitatissimum)* varieties under double cropping system in Tawa Command. Indian J Agron. 39:105-109.

Dybing, C., and D. Zimmerman. 1965. Temperature effects on flax (*Linum usitatissimum* L.) growth, seed production, and oil quality in controlled environments. Crop Sci. 5:184-187.

Fontana, F., D. Cremaschi, C. Vender, C. Maestrini, and L. Natarelli. 1996. Comparison of two spring sowing dates for linseed (*Linum usitatissimum* L.) cultivars. Rivista di Agronomia 30:248-251,896.

Ford, J., and D. Zimmerman. 1964. Influence of time of flowering on oil content and oil quality of flaxseed. Crop Sci. 4:653-656.

Green, A.G., and D.R. Marshall. 1981. Variation for oil quantity and quality in linseed (*Linum usitatissimum*). Aust J Agric Res. 32:599-607.

Gusta, L., B. O'Connor, and R. Bhatty. 1997. Flax (*Linum usitatissimum* L.) responses to chilling and heat stress on flowering and seed yield. Can J Plant Sci. 77:97-99.

Kraft, J., T. Kommedahl, and A. Linck. 1963. Histological study of malformation in flax seed after exposure to 31 ° C. Botanical Gazette 124:367-371.

McGregor, D.I., and R.B. Carson. 1961. Fatty acid composition of flax varieties. Can J Plant Sci. 41:816.

Painter, E., L. Nesbitt, and T. Stoa. 1944. The influence of seasonal conditions on oil formation and changes in the iodine number during growth of flaxseed. J Amer Soc Agron. 36:204-213.

Ransom, J.K., and D. Berglund. 2006. 2006 North Dakota barley, oat, rye and flax cultivar performance descriptions.

Shahidullah, M., U. Islam, M. Karim, and R. Mondol. 1997. Performance of four linseed varieties: at different dates of sowing. J Scientific and Industrial Res. 32:186-190.

Siddique, A., D. Wright, and S. Ali. 2002a. Effects of time of sowing on the quality of flax seed. Online Journal of Biological Sciences 2:538-541.

Siddique, A., D. Wright, S. Ali, and A. Mollah. 2002b. Effects of sowing dates on the phenology, seed yield and yield components of flax. Online Journal of Biological Sciences 2:366-369.

Sosulski, F.W., and R.F. Gore. 1964. The effect of photoperiod and temperature on the characteristic of flaxseed oil. Can J Agr Sci. 44:381-382.

Vick, B.A., C.C. Jan, and J.F. Miller. 2004. Second-year study on the inheritance of the reduced saturated fatty acid trait in sunflower seed. Proceedings 26th Sunflower Research Workshop, Fargo, ND.

Vrinten, P., Z. Hu, M.-A. Munchinsky, G. Rowland, and X. Qiu. 2005. Two *FAD3* desaturase genes control the level of linolenic acid in flax seed. Plant Phy. 139:79-87.

Table 1. Flax planting dates at two Iowa locations for years 2005 and 2006.

Location	Year	Planting Date		
Central IA	2005	4 April	15 April	25 April
NW IA	2005	8 April	18 April	28 April
Central IA	2006	11 April	21 April	5 May
NW IA	2006	11 April	21 April	5 May

Table 2. Mean monthly air temperature and rainfall in Central IA in 2005 and 2006. Mean is the average of data from 1951-2007.

Month	Air Temperature			Rainfall		
	2005	2006	Mean	2005	2006	Mean
	---------------------^{o}F † ----------------			------------------ in. ‡---------------		
March	38	38	36	1.38	2.93	2.05
April	55	56	50	3.24	4.30	3.51
May	60	62	61	4.38	2.15	4.50
June	74	72	70	4.87	0.81	4.86
July	76	76	74	4.10	5.56	4.02
August	72	72	72	6.76	6.16	4.20
September	69	61	64	4.36	7.51	3.23
October	54	50	52	0.35	2.49	2.33

† Tc = (5/9)x(Tf-32)
‡ cm=in. x 2.54
Information source: NWS CO OP

Table 3. Mean monthly air temperature and rainfall in NW IA in 2005 and 2006. Mean is the average of data from 1951-2007.

Month	Air Temperature			Rainfall		
	2005	2006	Mean	2005	2006	Mean
	--------------------^{o}F †-----------------			------------------ in. ‡----------------		
March	34	34	33	0.54	4.32	1.74
April	52	52	48	3.24	3.42	2.67
May	57	61	59	3.41	1.19	3.86
June	71	70	69	9.89	4.21	4.59
July	75	77	73	2.44	0.87	3.67
August	71	72	71	2.71	5.97	3.83
September	67	58	62	4.61	4.06	3.18
October	51	47	50	1.67	0.23	1.79

† Tc = (5/9)x(Tf-32)
‡ cm=in. x 2.54
Information source: NWS CO OP

Table 4. Growing degree days accumulated beginning 1 January until the actual planting date of each year.

	Planting Date		
	Early	Mid	Late
NW IA 2005	536	796	951
Central IA 2005	474	724	986
NW IA 2006	548	791	1055
Central IA 2006	638	910	1207

Fig. 1. Planting date effect on flax grain yield of five cultivars in NW IA in 2005.

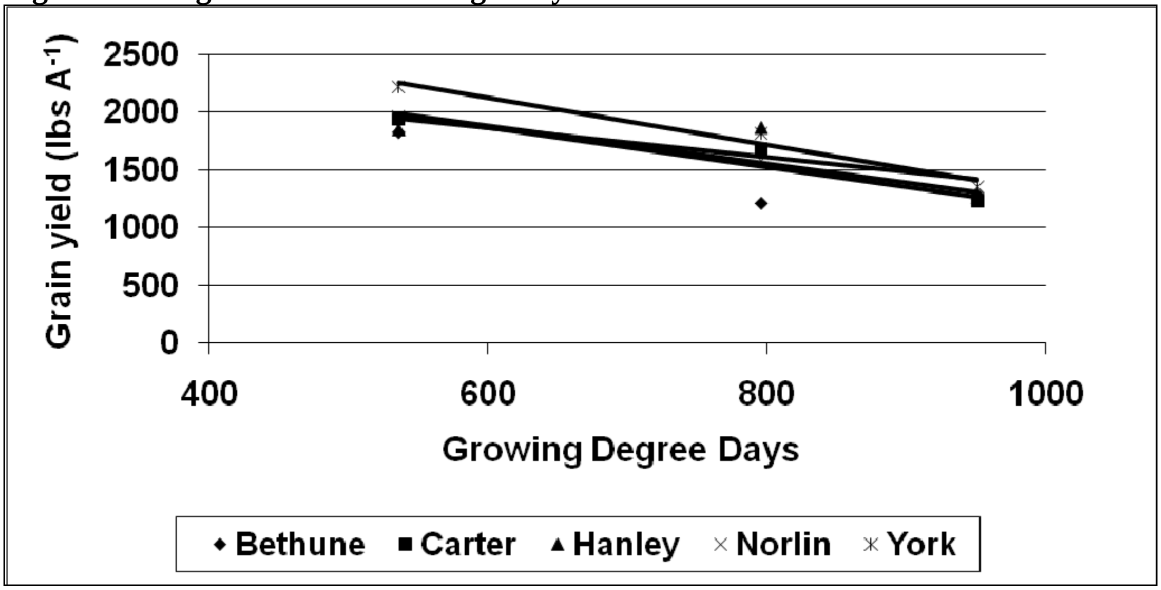


Fig. 2. Planting date effect on flax grain yield of five cultivars in Central IA in 2005.

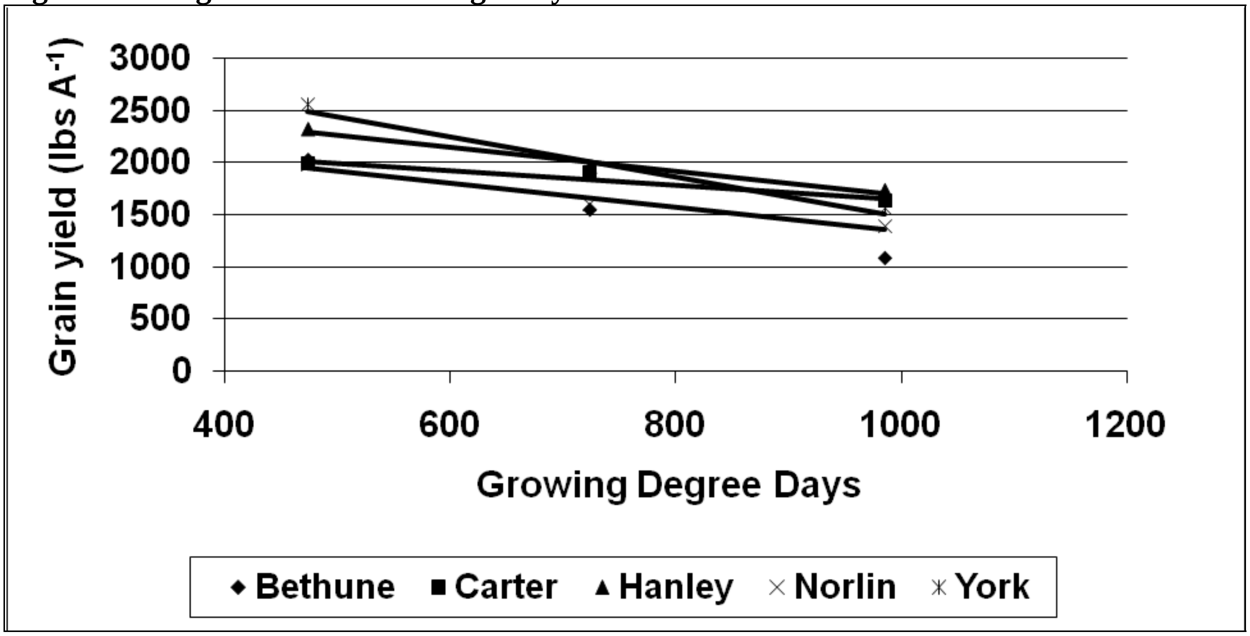


Fig. 3. Planting date effect on flax grain yield at NW IA and Central IA in 2006.

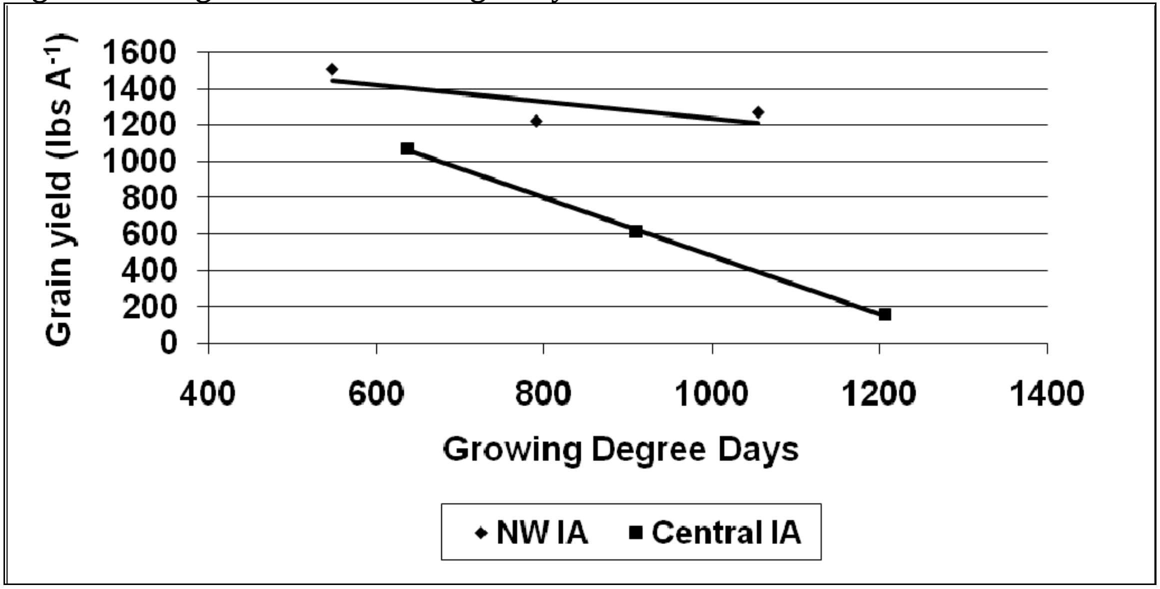


Fig. 4. Comparison of flax grain yield among five cultivars grown in NW IA in 2006.

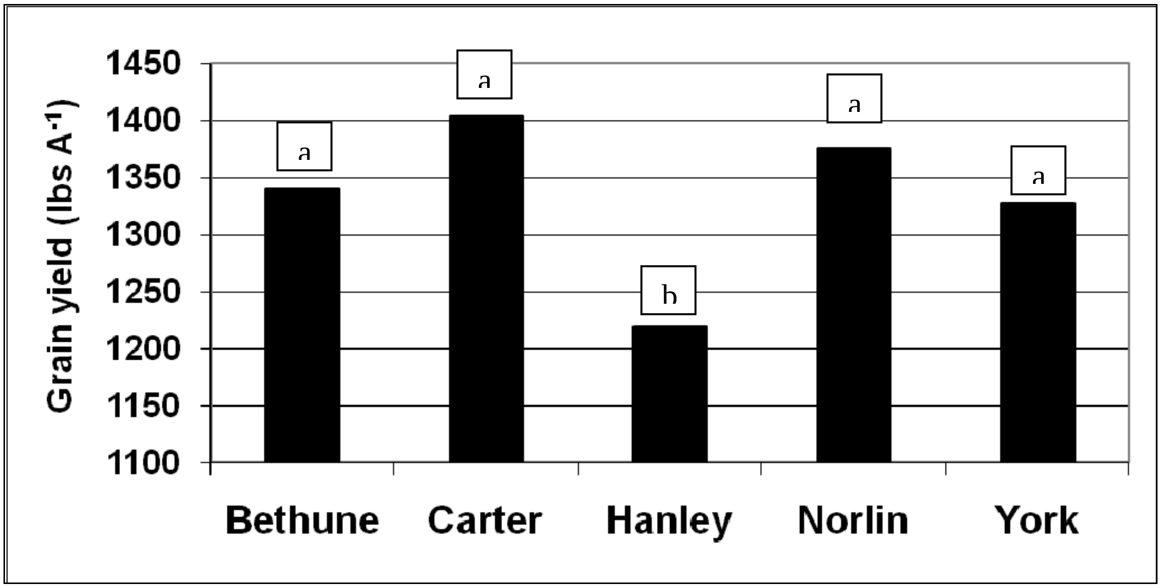


Fig. 5. Planting date effect on flax straw yield in NW IA and Central IA in 2005.

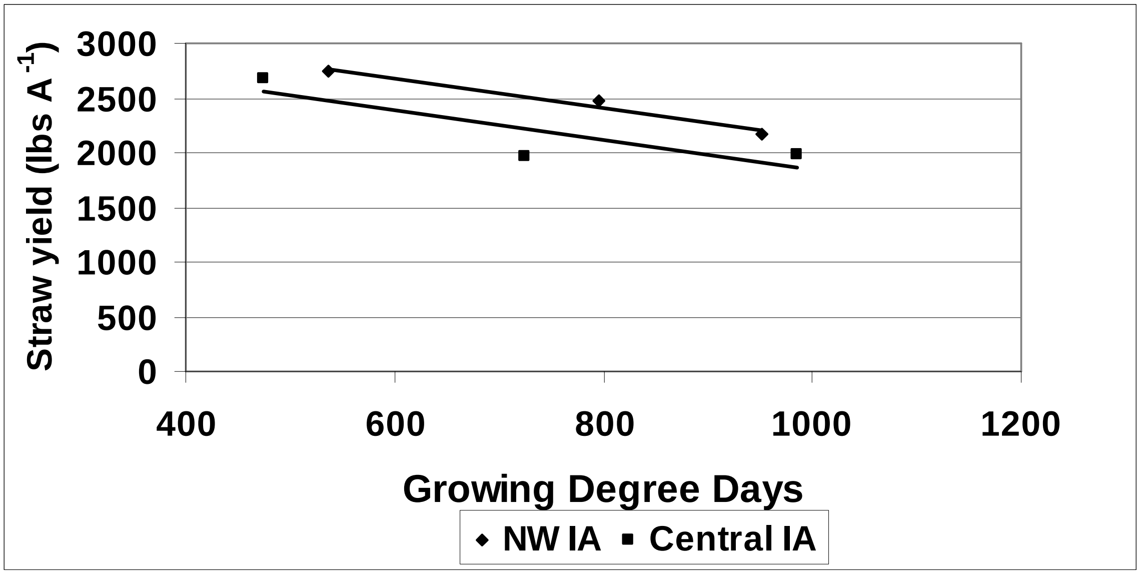


Fig. 6. Comparison of flax straw yield among five cultivars grown in Central IA in 2006.

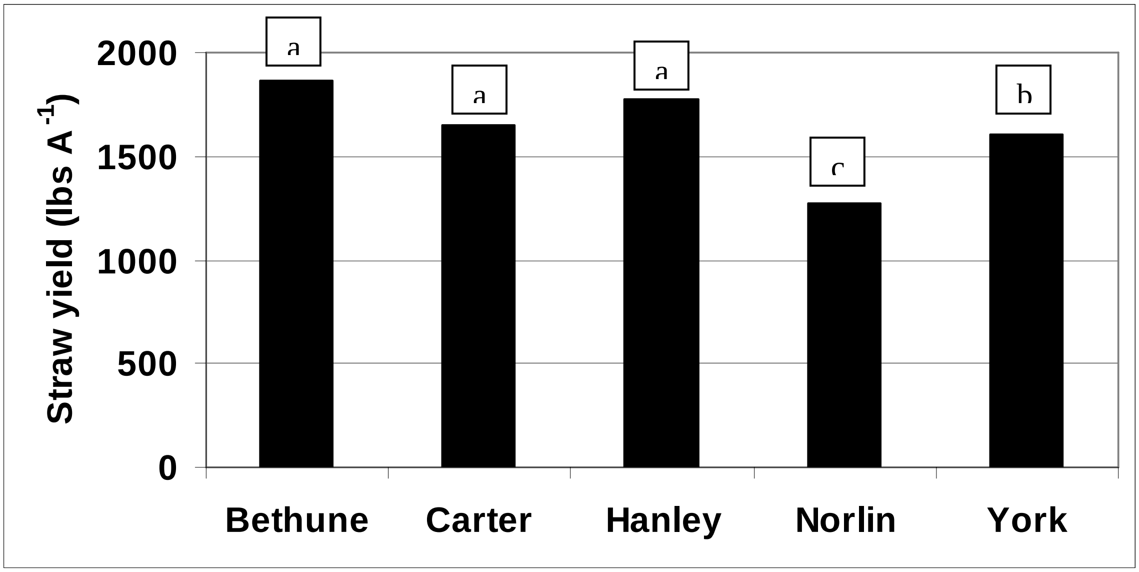


Fig. 7. Comparison of total oil content of flax grain among five cultivars grown in NW IA in 2006.

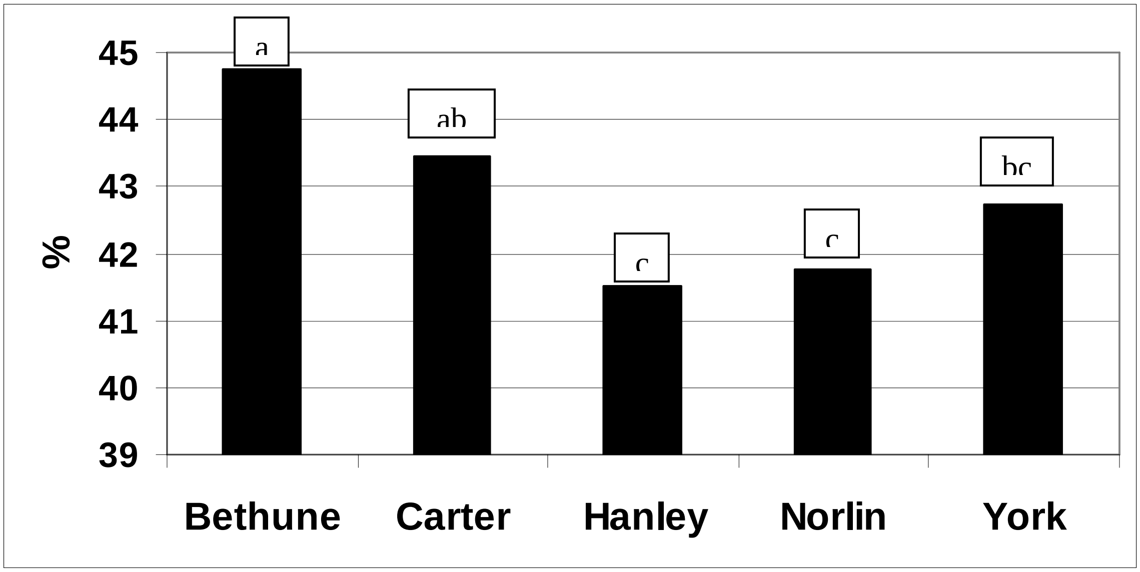


Fig. 8. Planting date effect on alpha linolenic acid (ALA) percentage of the oil of flax grain in NW IA in 2005 and Central IA in 2006.

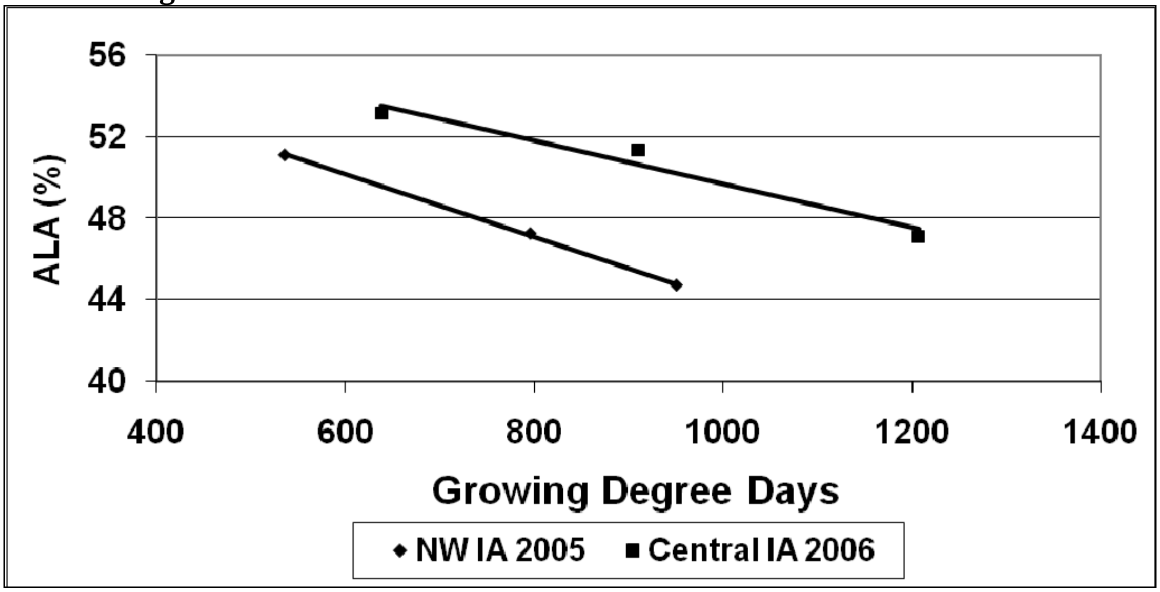


Fig. 9. Planting date effect on alpha linolenic acid (ALA) content of the oil of five flax cultivars in NW IA in 2006.

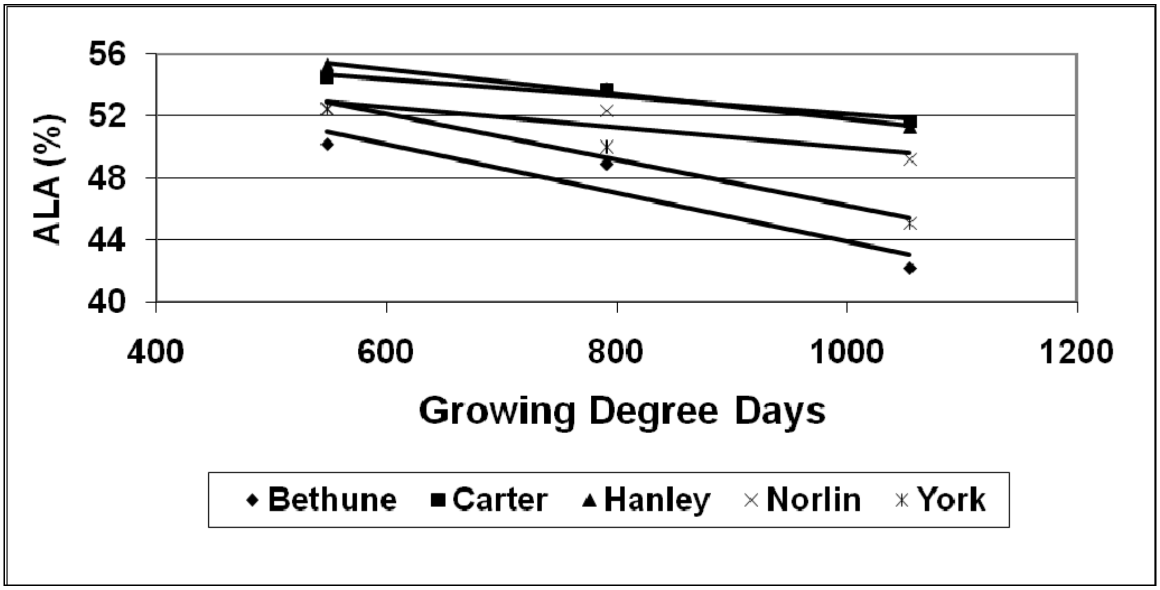


Fig. 10. Planting date effect on alpha linolenic acid (ALA) content of the oil of five flax cultivars in Central IA in 2005.

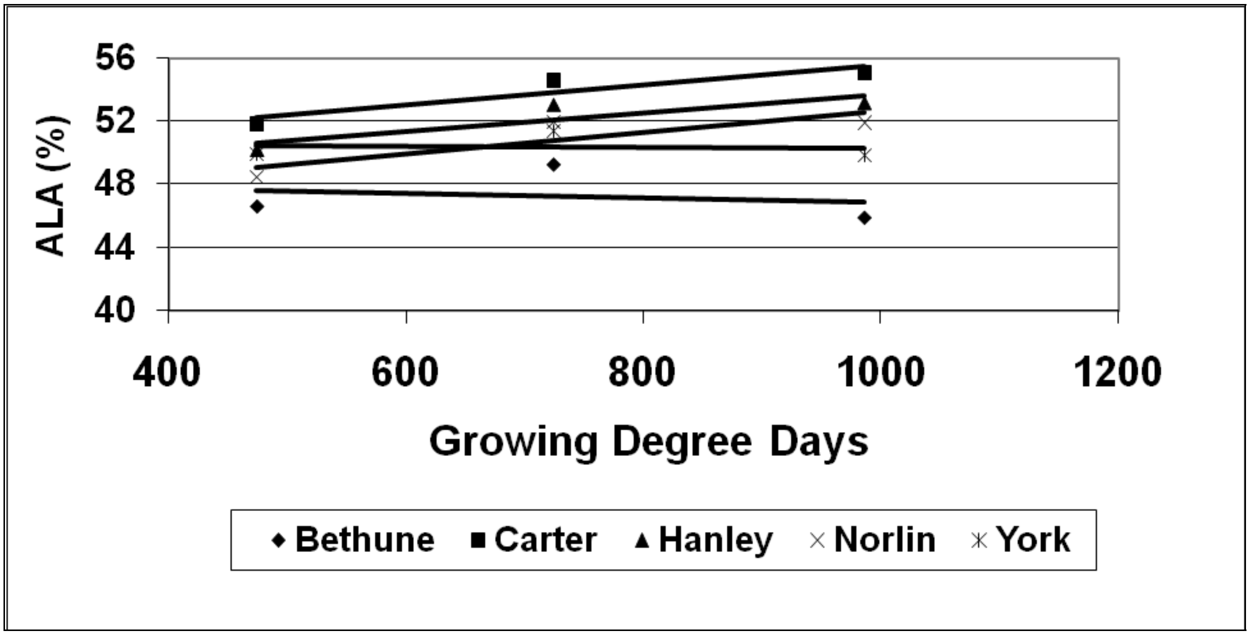


Fig. 11. Comparison of alpha linolenic acid (ALA) content of the oil of five flax cultivars grown in NW IA in 2005 and Central IA 2006.

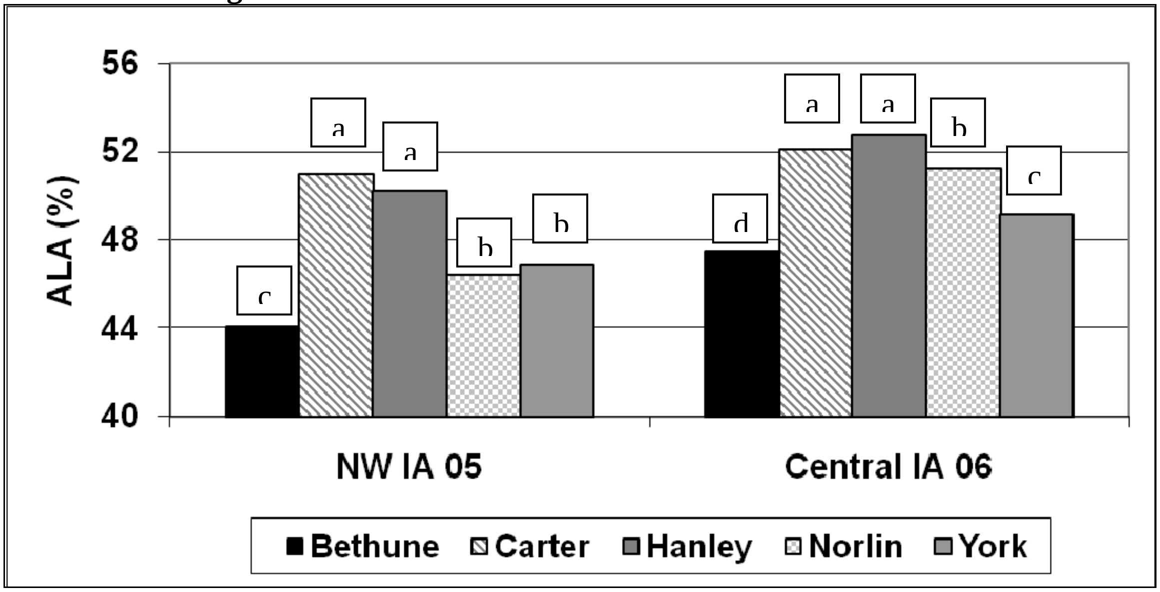


Fig. 12. Planting date effect on linoleic acid content of the oil of five flax cultivars in Central IA in 2005.

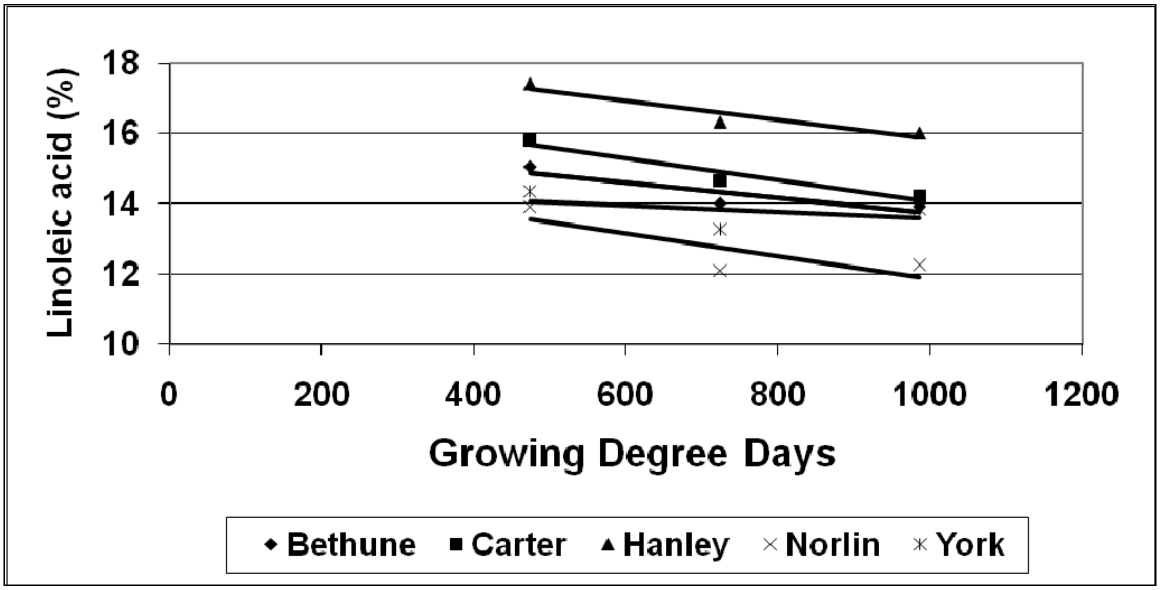


Fig. 13. Planting date effect on linoleic acid content of the oil of five flax cultivars in NW IA in 2006.

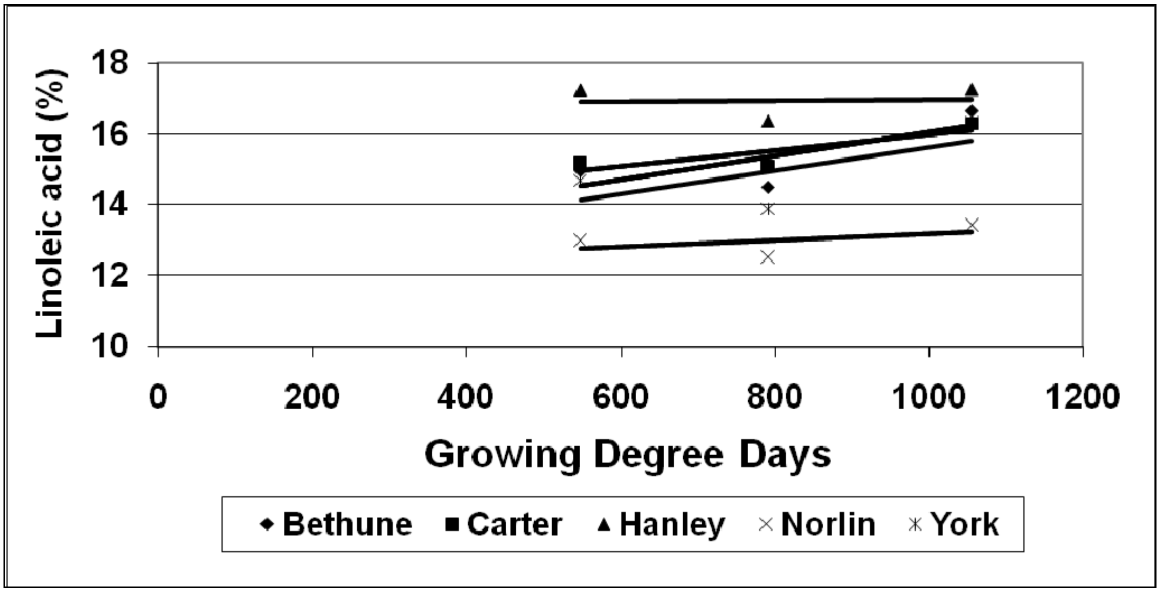


Fig. 14. Planting date effect on linoleic acid content of the oil of five flax cultivars in Central IA in 2006.

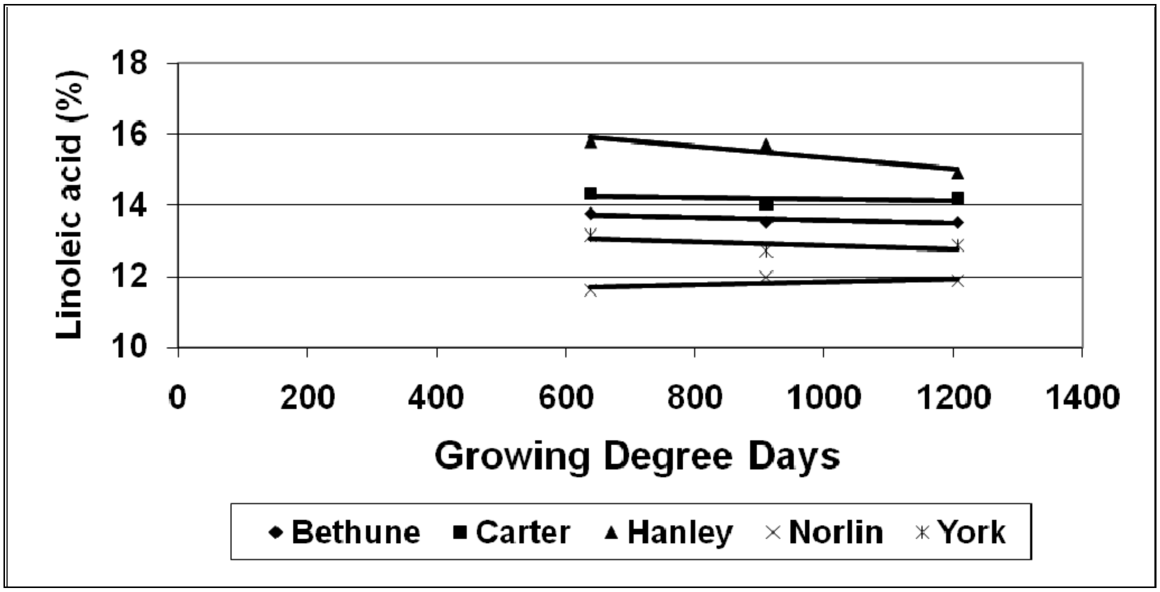


Fig. 15. Planting date effect on linoleic acid content of the oil of five flax cultivars in NW IA in 2005.

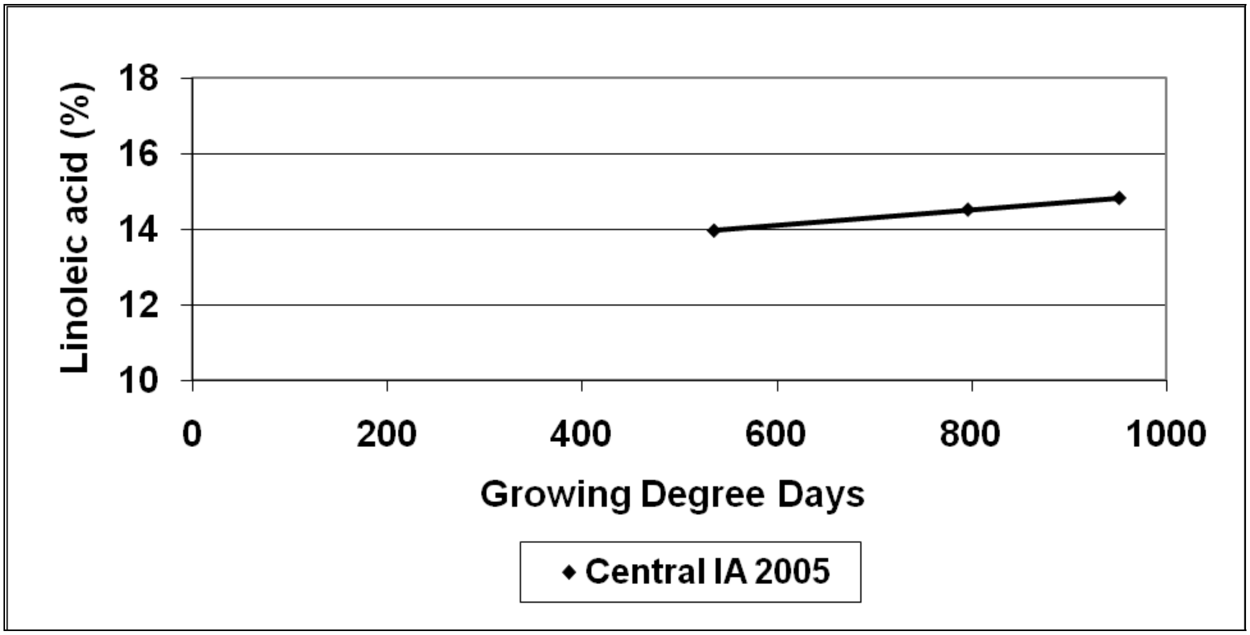


Fig. 16. Planting date effect on linoleic acid content of the oil of five flax cultivars in NW IA in 2005.

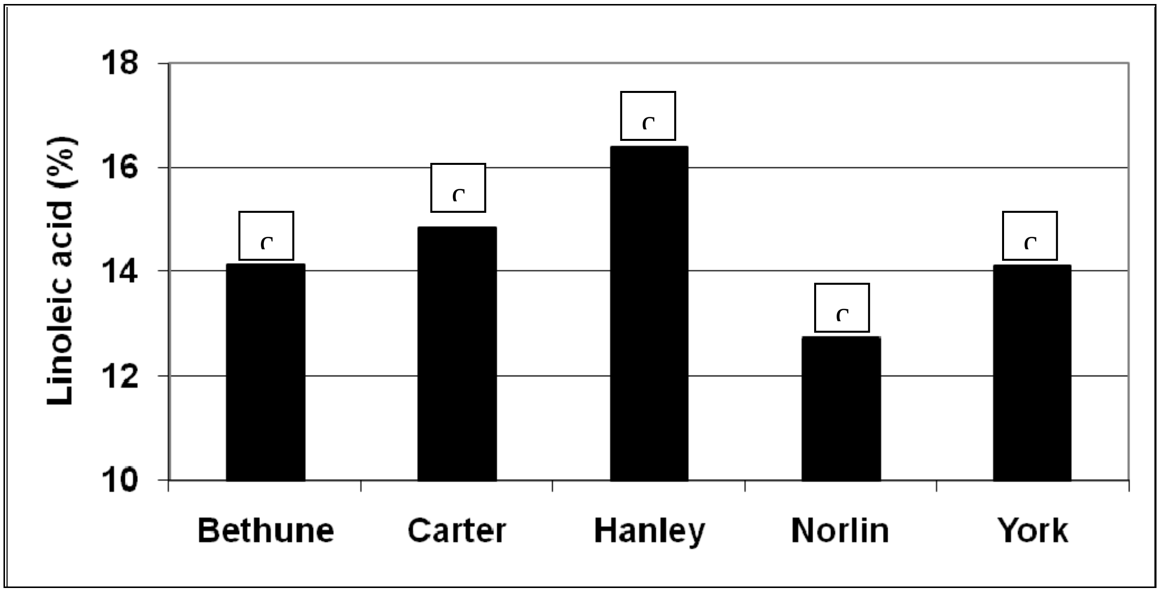


Fig. 17. Planting date effect on oleic acid content of the oil of five flax cultivars in NW IA in 2005 and Central IA 2006.

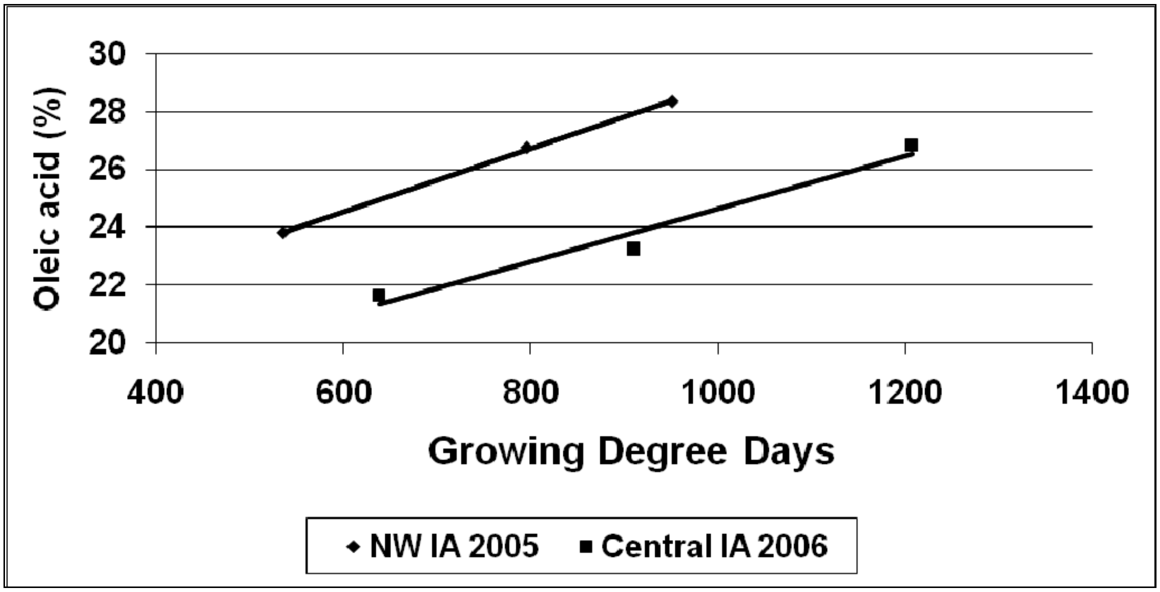


Fig. 18. Planting date effect on oleic acid content of the oil of five flax cultivars in Central IA 2005.

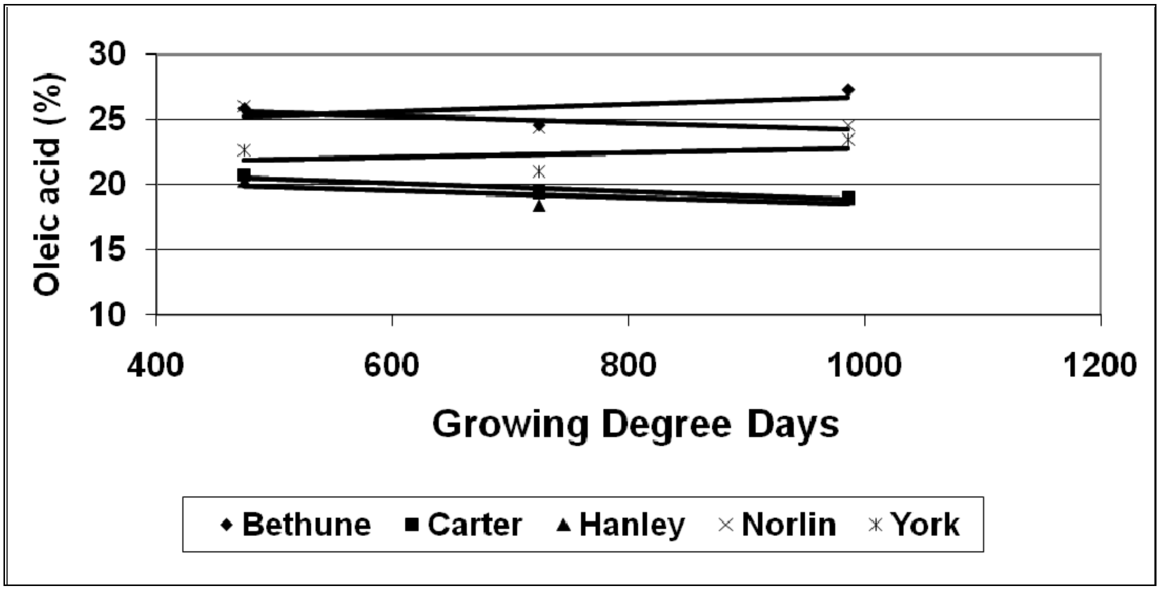


Fig. 19. Planting date effect on oleic acid content of the oil of five flax cultivars in NW IA 2006.

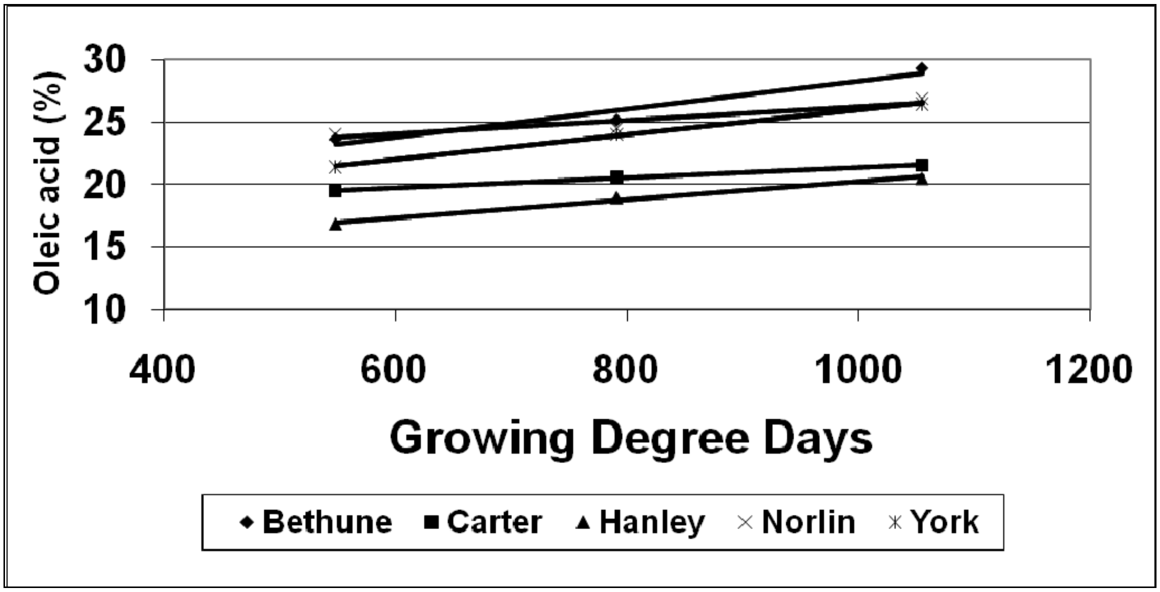


Fig. 20. Planting date effect on oleic acid content of the oil of five flax cultivars in NW IA 2005 and Central IA 2006.

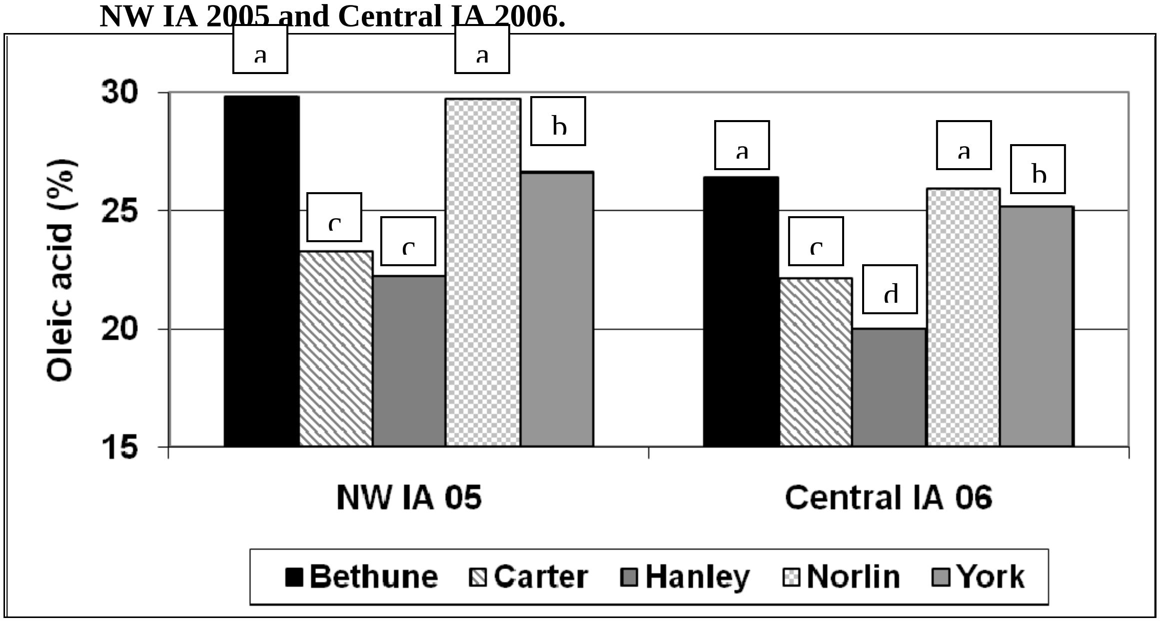


Fig. 21. Planting date effect on stearic acid content of the oil of five flax cultivars in NW IA in 2005 and 2006.

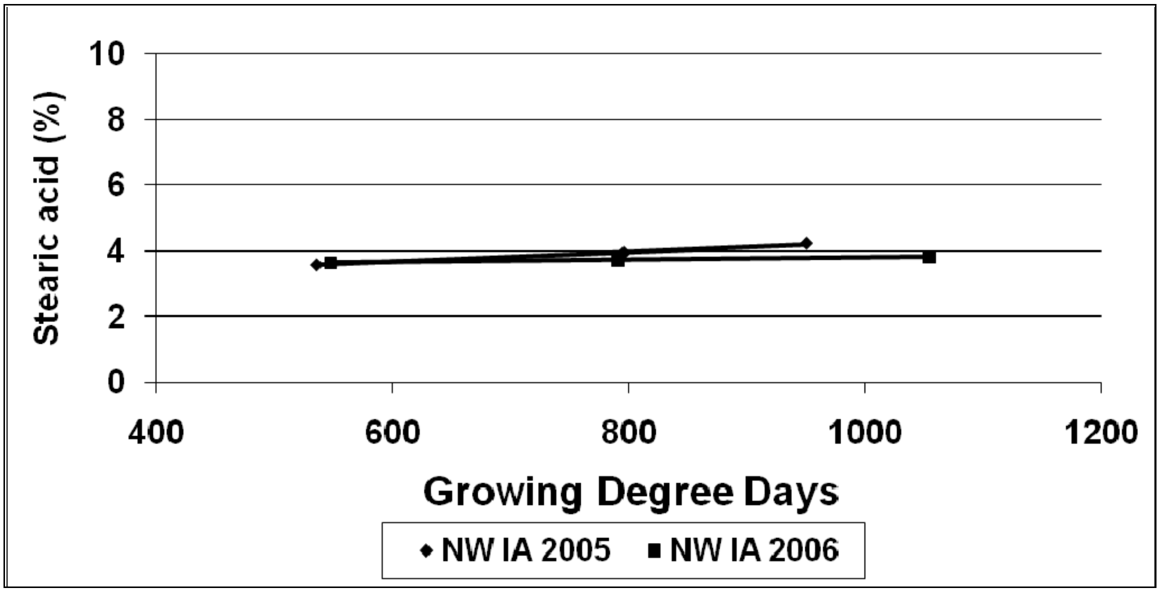


Fig. 22. Planting date effect on stearic acid content of the oil of five flax cultivars in Central IA 2005.

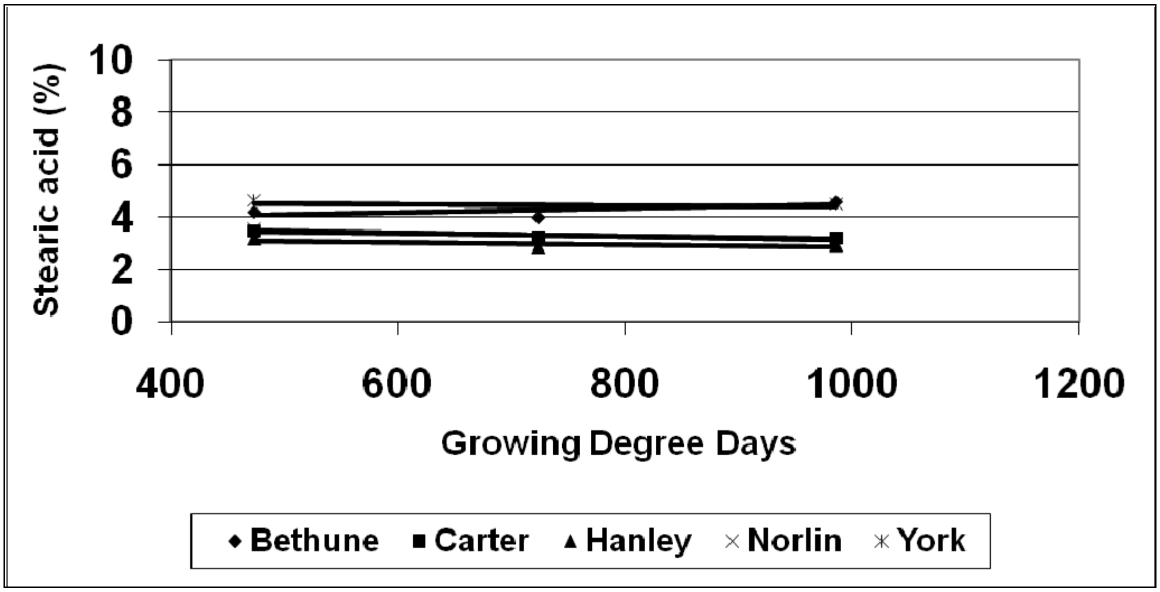


Fig. 23. Planting date effect on stearic acid content of the oil of five flax cultivars in Central IA 2006.

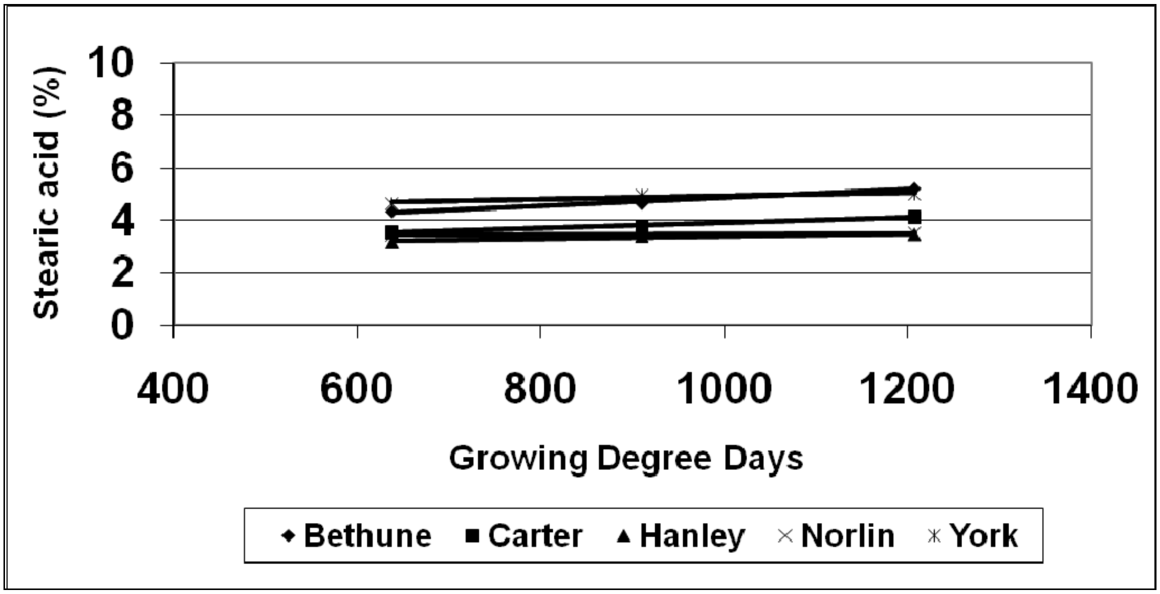
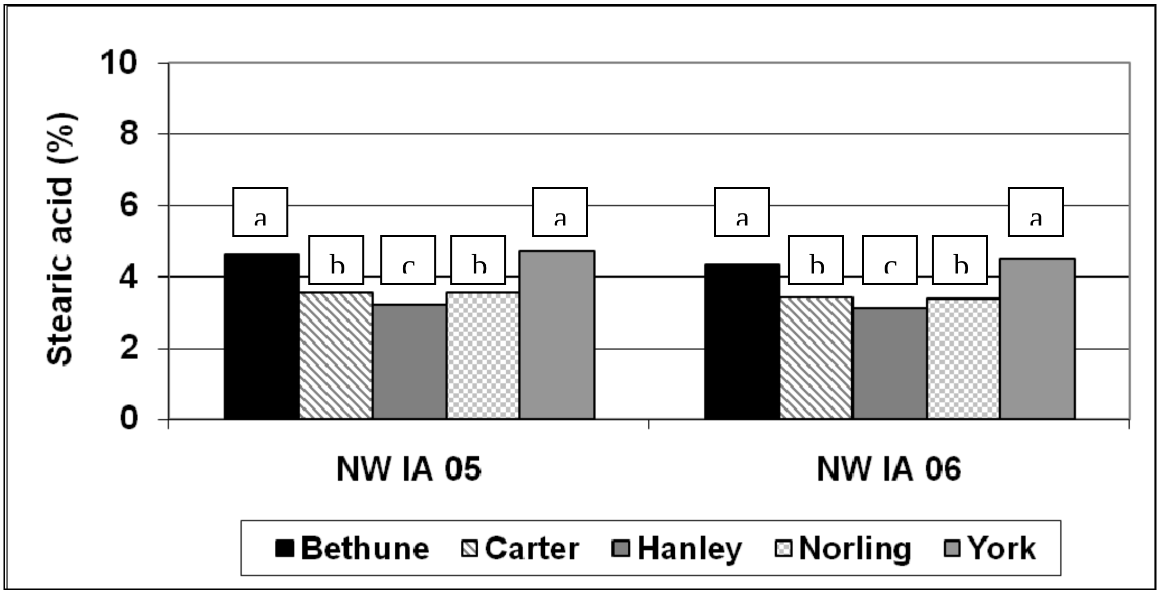


Fig. 24. Planting date effect on stearic acid content of the oil of five flax cultivars in NW IA 2005 and 2006.



CHAPTER IV

Weed management strategies for organic flax production

Introduction

Flax does not compete well with weeds because it produces little shade and uses water and soil nutrients less efficiently than most weed species (Gruenhagen and Nalewaja, 1969). Friesen (1986) stated that yield reductions caused by weeds would be a certainty, if flax producers were to eliminate herbicides. A new market for organically produced flaxseed has developed in Iowa and farmers are interested in producing and selling organic flax. Due to organic production regulations, weeds cannot be controlled using chemical herbicides. Because flax is a poor competitor with weeds, documentation of alternative weed management strategies for flax production will provide researchers and farmers with several options for managing weeds.

Two different studies conducted in Manitoba, Canada concluded that yields of flaxseed and flax straw were significantly decreased due to competition from weeds. Compared to wheat, barley or oat yields, losses to flax yield were consistently greater (Friesen and Shebeski, 1960). Flax was negatively affected by as few as 11 plants m^{-2} (121 plant ft^{-2}) of wild mustard (*Brassica kaber* var. pinnatifida) (Burrows and Olson, 1955) and 33 plants m^{-2} (108.2 plants ft^{-2}) of cow cockle (*Vaccaria vulgaris*) (Alex, 1968). In North Dakota, flax grain yield decreased with competition from approximately 54 plants m^{-2} (5 plants ft^{-2}) of wild buckwheat (*Polygonum convolvulus* L.) (Gruenhagen and Nalewaja, 1966).

These studies show that weed competition during flax growth can negatively affect grain and straw yield. To manage weeds in flax, pre and post-emergent herbicides are commonly used. Post-emergent broadleaf and grass herbicides are applied early when flax plants are 2 to 8 in. (5 to 20 cm) tall and weeds have germinated (Berglund and Zollinger, 2002).

A study conducted in Saskatchewan, Canada compared four levels of post-emergence weed control concomitantly with three seeding rates in flax: no control, broadleaf control, grass control and broadleaf and grass control. Control of broadleaf and grass weeds resulted in the highest grain yield. In addition, for every 100 seed m^{-2} (1075 seed ft^{-2}) increase in the flax seeding rate, broadleaf and grass weed yields decreased by 50 kg ha^{-1} (44.5 lb A^{-1}) and 23 kg ha^{-1} (20.5 lb A^{-1}), respectively. In all four levels of weed control, flax grain yield responded positively to a higher flax seeding rate (Stevenson and Wright, 1996).

For farmers who practice organic methods or who want to decrease their use of chemicals and grow flax, alternatives to herbicides are a must. Viable weed management strategies for flax production are important due to the potential long-term effects of weeds on these reduced chemical systems. Albrecht and Sommer (1998) measured an average increase from 4050 to 17,320 weed seed m^{-2} (377 to 1611 weed seed ft^{-2}) in the soil seedbank three years after conversion from a conventional to an organic production system in the UK. The performance of future crops planted on flax fields could be affected, if weeds are not managed during the flax year.

To combat weeds during the flax year, reduced chemical producers can use cultural practices such as delayed planting with pre-seeding tillage to control early germinating weeds (Berglund and Zollinger, 2002); however, delayed planting may decrease flax grain yield (Dixit et al., 1994; Fontana et al., 1996; Shahidullah et al., 1997). Other strategies include varying crop rotation and tillage methods (Sarvis and

Thysell, 1936; Puhr, 1962; Krall et al., 1965); decreasing row spacing (Klages, 1932; Dillman and Brinsmade, 1938; Alessi and Power, 1970); varying seeding rate (Albrechtsen and Dybing, 1973; Gubbels, 1978); varying seeding rate and row spacing (Hassan et al., 2005); intercropping flax with a legume (Klebesadel and Smith, 1959); and varying rates of nutrient application (Culbertson et al., 1961).

These studies used various cultural practices to control weeds during the flax year to compare the resulting flax grain yields with weed biomass production or weed stand counts. The majority of these studies do not describe how weeds were managed in the materials and methods section. One study did compare hand-weeded and weedy plots (Alessi, 1970). If a herbicide was applied to control weeds in any of these studies, then an accurate evaluation of the cultural treatment's performance was not assessed. Ideally, splitting the experimental plots and hand-weeding half the plot accurately assesses the performance of the weed management strategy.

The objective of this research addresses farmers' need to know how alternative weed management strategies can affect flax grain yield, straw yield, weed biomass yield, underseeding biomass yield, total oil content, alpha linolenic acid (ALA) percentage of the oil and the fatty acid profile. Our hypotheses are: 1) greater weed biomass will negatively affect flax grain and straw yield and total oil content, ALA percentage and the fatty acid profile and 2) flax grain yield, straw yield, total oil content, ALA percentage as well as the four other fatty acids in the profile will be negatively affected by the herbicide treatment as compared to the biological and mechanical weed management strategies.

Materials and methods

Description of locations

The experiment was conducted in 2005 and 2006 at two locations in Iowa: at the ISU Agronomy and Ag Engineering Research Farm near Boone, IA (Central IA) (42.0^o N, 93.0^o W, elevation 354 m, (1161 ft)), on a Webster-Nicolet, fine-loamy, mixed, superactive, mesic, Typic Engoquoll soil and at the ISU Northwest Research and Demonstration Farm near Sutherland, IA (NW IA) (42.9^o N, 95.5^o W, elevation 445 m, (1461 ft)), on a Primghar silty clay loam, fine-silty, mixed, mesic Aquic Hapludolls soil. Soil test results at Central IA indicated a soil pH of 7.3 (2005) and 7.4 (2006), phosphorus (Bray P_1) levels of 11 ppm (2005) and 12 ppm (2006), potassium levels of 93 ppm (2005) and 109 ppm (2006) and an organic matter content of 5.6% (2005) and 5.2% (2006). At NW IA, the soil test results indicated a soil pH of 5.9, phosphorus (Bray P_1) level of 21 ppm, potassium level of 152 ppm and organic matter content of 3.8% for both years.

Seedbed preparation

The specific soil conditions in each year at each location determined the primary and secondary tillage used in the spring. At Central IA, in 2005 and 2006, the field was tandem disked followed by application and immediate incorporation of 66.1 kg N ha^{-1} (59 lb N A^{-1}) as urea. Plots were field cultivated prior to each planting date. Additionally in 2005, 289.8 kg (130.4 lb) of phosphate fertilizer product (0-46-0) was applied. At NW IA, in 2005 and 2006, experimental areas were initially disked. Each year, 59.4 kg N ha^{-1} (53 lb N A^{-1}) was applied as urea. Plots were field cultivated prior to each planting date.

Treatments

<u>Project 1</u> was replicated six times in 2005 and four times in 2006. The experimental design was a randomized complete block with weed management strategies

as the main plots and unweeded versus hand-weeded treatments as subplots. In 2005, plots measured 4.3 m x 7.6 m (14 ft x 25 ft) and in 2006, 6.4 m x 7.6 m (21 ft x 25 ft). Flax was drilled with a 2.1 m (7 ft) wide Tye no-till drill with 0.179 m (7 in.) row spacing at a rate of 56 kg ha^{-1} (50 lb A^{-1}). In 2006, the grass seeder tubes on the Tye no-till drill were offset from the main hopper box in order to seed the red clover (*Trifolium pretense* L.) in between the flax rows as opposed to directly in the flax row. In Central IA, the herbicide treatment was applied when weeds were present and flax was 15.2 cm (6 in.) tall in 2005 and when flax was beginning bud stage in 2006 33.0 cm (13 in.) In 2005, dimethylamine salt of 2-methyl-4-chlorophenoxyacetic acid (48.58% a.i.) was applied on 20 May and sethoxydim (18% a.i.) was applied on 24 May. In 2006, herbicides were tanked mixed and applied on 1 June. Due to field conditions in 2006, the herbicide treatment was applied one week later than optimal.

The main effect treatments were:

- drilled flax, no underseeding (control)
- drilled flax + broadcasted red clover 16 kg ha^{-1} (14 lb A^{-1}) (biological)
- drilled flax + sethoxydim (18%) 2.34 liters ha^{-1} (2 pints A^{-1}) and dimethylamine salt of 2-methyl-4-chlorophenoxyacetic acid (48.58%) 0.59 liters ha^{-1} (0.50 pint A^{-1}) herbicides (chemical)

Flax cultivar ‘Norlin’ was planted on 4 April 2005 and 11 April 2006. Planting dates were based on the local planting date for small grain crops. In Central IA the majority of small grains were planted before 10 April in 2005 and 23 April in 2006 (M. Smith, personal comm., 2006).

Project 2 was replicated four times at both Central IA and at NW IA in 2005 and 2006. Plots measured 4.3 m x 7.6 m (14 ft x 25 ft). In Central IA flax was drilled with a 2.1 m (7 ft) wide Tye no-till drill with 0.179 m (7 in.) row spacing. In 2006 at Central IA, the grass seeder tubes on the Tye no-till drill were offset from the main hopper box in order to seed the red clover in between the flax rows as opposed to directly in the flax row. In NW IA, flax was drilled with a 2.4 m (8 ft) wide Massey Ferguson wide end-wheel drill with single disk openers and 0.179 m (7 in.) row spacing. At both locations, flax cultivar ‘Norlin’ was seeded at a rate of 56 kg ha^{-1} (50 lb A^{-1}). In Central IA, the herbicide treatment was applied when weeds were present and flax was 15.2 cm (6 in.) tall in 2005 and when flax was beginning bud stage in 2006 33.0 cm (13 in.) In 2005, dimethylamine salt of 2-methyl-4-chlorophenoxyacetic acid (48.58% a.i.) was applied on 20 May and sethoxydim (18% a.i.) was applied on 24 May. In 2006, herbicides were tank mixed and applied on 1 June. Due to field conditions in 2006, the herbicide treatment was applied one week later than optimal. In NW IA the herbicides were tank mixed and applied on 24 May 2005 and 26 May 2006.

The seven weed management treatments categorized as biological, mechanical or chemical are described as:

Control:

- drilled flax, no underseeding (control)

Biological:

- drilled flax + broadcasted red clover 16 kg ha^{-1} (14 lb A^{-1}) (red clover)
- drilled flax + broadcasted alfalfa (*Medicago sativa*) 18 kg ha^{-1} (16 lb A^{-1}) (alfalfa)

- drilled flax + broadcasted grass/legume mix [orchardgrass (*Dactylis glomerata*) 2.24 kg ha^{-1} (2 lb A^{-1}), timothy (*Phleum pretense*) 3.4 kg ha^{-1} (3 lb A^{-1}), red clover 4.5 kg ha^{-1} (4 lb A^{-1}), and alfalfa 4.5 kg ha^{-1} (4 lb A^{-1})] (grass legume)

Chemical:

- drilled flax + sethoxydim (18%) 2.34 liters ha^{-1} (2 pints A^{-1}) and dimethylamine salt of 2-methyl-4-chlorophenoxyacetic acid (48.58%) 0.59 liters ha^{-1} (0.50 pint A^{-1}) herbicides (chemical)

Mechanical:

- broadcasted flax (broadcast)
- flax cross drilled at half seeding rates 28 kg ha^{-1} (25 lb A^{-1}) at 30^{o} angles in two directions (2-way)

In 2005, flax was planted on 4 April in Central IA and on 8 April in NW IA. In 2006 at both locations, flax was planted on 11 April. Flax experiments were planted on land previously seeded to soybeans; weeds had been managed using chemical herbicides. A minimum amount of soybean residue was observed.

Monthly averages of the precipitation and temperature values were measured for each site. Temperature values for each individual growing season were measured and increased with a delayed planting date (Tables 1 and 2).

Data collection

Flax was harvested when experimental plots were physiologically mature, i.e. 90% of the bolls were a dark brown color as suggested by Berglund and Zollinger (2002). Project 1 was harvested on 17 and 18 July 2005 and 19 July 2006 at Central IA. Project 2 was harvested in Central IA on 14 July 2005 and 17 and 18 July 2006 and in NW IA on

28 July 2005 and 20 July 2006. Four quadrates (1 ft^2) were randomly placed on the ground encompassing two rows and two interrows of planted flax. Pruning shears were used to cut flax plants at the height of the quadrant 0.0245 m (1 in.). Immediately after harvest, weeds and underseeding biomass were separated from flax plants. Flax plants were placed into cloth bags and dried at ambient air temperature for three days. All other fractions were placed in paper bags and dried at 60 C (140 F) for seven days. Underseeding and weed biomass were weighed to determine total dry matter yield for each fraction. After the flax was air dried in 2005, it was hand threshed; in 2006, it was machine threshed using an Almaco small bundle thresher. Quadrates from individual plots were combined and flaxseed was cleaned using a South Dakota seed cleaner in 2005 and a Westrup LA-LS laboratory air-screen cleaner in 2006. Cleaned samples had less than 0.5% foreign matter (FM). Percent moisture of the seed was measured using the ISO standard procedure for flax grain moisture; one gram (0.035 oz) of flaxseed was baked at 103 C (217.4 F) for three hours (V. Barthet, personal comm., 2006). After threshing, the straw was dried at 60 C (140 F) for five days and weighed.

The total oil content of flaxseed was non-destructively analyzed using a Newport 4000 Nuclear Magnetic Resonance Analyzer from Oxford Analytical Instruments Limited. A 40 ml (1.4 oz) sample was used.

Gas chromatography (GC) was used to determine the fatty acid profile of the oil content. Fatty acid composition is expressed as the percent by weight of the C16 to C24 saturated fatty acids divided by the weight of all fatty acids (Vick et al., 2004). A whole or half flaxseed was placed in a GC autosampler vial and crushed with a thin (end-flattened) glass rod. A 1.0 – 1.5 ml (0.03 – 0.05 oz) of a hexane-chloroform-0.5 M sodium methoxide in methanol (75:20:5, v/v) solution was added to the vial. The sample was injected into a Hewlett-Packard 589-gas chromatograph containing a DB-23 capillary column (30 m x 0.25 mm, J&W Scientific), which was held at 190 C (374 F) for five minutes, then increased to 220 C (428 F) at 10 C $minute^{-1}$ (50 F $minute^{-1}$). The sample was held at 220 C (428 F) for one minute, then increased to 240 C (464 F) at 20 C $minute^{-1}$ (68 F $minute^{-1}$), and finally held at 240 C (464 F) for one and a half minutes. The total run time was 11.5 minutes.

Statistical analysis

Statistical analysis was conducted at the individual site-year level for both projects to assess how the individual parameters responded to the various treatments. The site-year is the data from each location in each year. Statistical analysis was performed using the least square means for the MIXED model procedure of the Statistical Analysis System (SAS). Tests of differences among lsmeans were made at the 0.05 probability level and different treatment means were compared using pdiffs.

Results and discussion

Project 1

Grain yield

In 2005, grain yield was not statistically different among the main effect treatments or between the unweeded and weed-free subplots (Tables 3 and 4). Grain yield averaged 1413 lb A^{-1} regardless of the treatment. More weeds were present in 2006 and grain yield did not differ among the main effect treatments, averaging 1058.3 lb A^{-1}; however in the subplots grain yield was statistically higher in the weed-free plots yielding 1176.5 lb A^{-1} compared to 940.1 lb A^{-1} in the unweeded plots (Table 4). In 2006, an increased yield in the weed-free treatment suggests that managing weeds by hand weeding can help increase grain yield but using a red clover or herbicide treatment will not. The weight of harvested weed biomass ranged from 10.7 to 305.7 lb A^{-1} in 2005 and 616.2 to 1373.2 lb A^{-1} in 2006. Due to this significant difference in weed pressure, years were analyzed separately (Table 3).

From visual observations and the measured dry weight of the red clover underseeding, it did not establish well (data not shown). Therefore, weed biomass and underseeding biomass data, referred simply as biomass, were combined when analyzed to show an overall effect of competition to the flax plants. In 2005, non-flax biomass was the same among all the main effect treatments but was significantly less in the weed-free subplots as compared with the non-weeded subplots (Tables 3 and 4). In the non-weeded subplots the herbicide treatment did significantly reduce the non-flax biomass when compared to the control and red clover which were statistically similar. Because the red clover did not establish well, it did not provide weed control. In 2006, an interaction occurred between the treatments and the subplots (Table 5).

In 2006, weeds were not controlled as well in the herbicide treatment as in 2005. The herbicide application was applied late in 2006 due to spring weather conditions. Therefore, poor herbicide efficacy could be attributed to the time of application, weather conditions or increased weed pressure of the specific field site. None of these individual factors were measured or included in analysis of the weed biomass data to account for this difference in control.

Although the red clover treatment did not improve flax grain yield, it was able to compete with weeds following flax harvest (Table 6). Weed growth occurred after flax was harvested in late July. To assess weed control of late summer weeds prior to frost by competition from an underseeding; an additional harvest of biomass from all treatments was taken 60 days following flax harvest in 2006. The combined underseeding and weed biomass data were not statistically different among the main effect treatments (Table 7). Of the non-flax biomass present in the red clover treatment, red clover biomass represented half, 1658 lb A^{-1}, of the total biomass, 3031.3 lb A^{-1}. Non-flax Biomass in the control and herbicide treatments yielded 2404.7 lb A^{-1} and 2974.4 lb A^{-1}, respectively and were 100% weeds. Plots were only hand-weeded during the months of May and June.

These levels of weed biomass were similar to the average production on an organic farm. During these same years, on average organic farmers harvested 1705 lb A^{-1} red clover biomass and 752 lb A^{-1} weed biomass 60 days following flax harvest (data not shown).

Oil

Total oil content of the flaxseed in 2005 was significantly higher averaging 48.2% compared to 41.3% in 2006; however, none of the treatments in either year influenced the percent oil (Table 8). The difference between years could be attributed to a later planting date in 2006 on 11 April compared to 4 April 2005 and different climatic conditions.

Fatty acid profile

The fatty acid profile of the flax was only measured in 2006. Alpha linolenic acid (18:3) acid content was significantly lower in the herbicide treatment at 53.4% compared to similar higher yields of 54.3% in both the control and red clover treatments (Table 9). Additionally, the unweeded treatment yielded higher at 54.3% compared to 53.7% in the weed-free (Table 10). Linoleic (18:2), oleic (18:1) and stearic (18:0) acids were significantly higher in the herbicide treatment as compared to the red clover and control treatments. In the weed-free treatments, oleic acid was significantly higher. Palmitic acid (16:0) content was not statistically different in any of the treatments. Linoleic, stearic and oleic acids measured higher percentages in the herbicide and weed-free treatment as compared to ALA acid which measured a higher percentage in the red clover, control and unweeded treatments.

Although unknown few studies exist that have assessed field level treatment effect on individual fatty acids. Friesen (1986) measured oil content and the iodine number which is the measurement of the unsaturation of the oil. Friesen's results show that oil content decreased from 42.9% without weeds to 41.9% with weeds and the iodine value decreased from 180 without weeds to 175 with weeds. The higher the iodine value the more unsaturated the fat. This study suggests that a weedier field will reduce the unsaturated fats, i.e. ALA. However this study did not measure the individual fatty acid profile. Our study contradicts these results suggesting that a weedier field will result in a more unsaturated fatty acid profile, i.e. ALA content. Because ALA content is affected by high temperatures (Chapter 3), a weedier field may be cooler during hot summers and instead of competing with flax plants for nutrients, it may create a micro climate favorable to ALA production.

Project 2

The predominant species, listed in order of quantity, were: giant foxtail (*Setaria faberi*), lambsquarter (*Chenopodium album*), Pennsylvania smartweed (*Polygonum pennsylvanicum*), waterhemp (*Amaranthus rudis*), common cocklebur (*Xanthium strumarium*), barnyardgrass (*Echinochloa crus-galli*), and fall panicum (*Panicum *dichotomiflorum*). Although some weed emergence was observed during flax establishment, when flax reached 15 in. in height weed growth slowed. It was observed that the majority of weed growth occurred after leaf drop around 20 June. Between 20 June and end of July when the crop is harvested, all weeds took advantage of an open canopy to grow.

Grain yield

In Central IA, more weed biomass was present in 2006 compared to levels in 2005 (Table 11). Due to this increase in weed competition between years, locations were analyzed separately to assess how the treatments in each site-year compared. In two of the four site-years, grain yield was different among the seven treatments (Table 12). In Central IA in 2005, the broadcast treatment yielded significantly less grain (914 lb A^{-1}) compared to the other treatments. Although stand counts of the flax plants were not taken, visual observations showed a poor stand in this treatment in all four blocks, which could explain the increased weed biomass. The amount of weed biomass harvested from this treatment was 1822.4 lb A^{-1} compared with the weed biomass harvested from the other treatments ranging from 110.7 to 623.3 lb A^{-1} (Table 11). A poor stand count could be attributed to poor seeding by the Brillon drill or the operator.

Without a weed-free check, the effect of weed biomass on flax grain yield is only suggestive. However, results from Project 1 suggest that flax grain yield is negatively affected by increased weed pressure when the weed pressure is greater than a certain threshold. Therefore, the high weed biomass harvested from this plot coupled with low grain yields support the conclusions from Project 1 that weed pressure negatively affects flax grain yield. A specific threshold, over which weed biomass must accumulate to affect flax grain yield, was not a part of this research.

In 2006 at NWIA, grain yield was significantly higher in the herbicide (1381.7 lb A^{-1}) and control (1245.6 lb A^{-1}) treatments, compared to the other treatments, which averaged 1098.9 lb A^{-1} (Table 12). The amount of weed biomass in the herbicide plots was 53.9 lb A^{-1}, which was significantly less than the other treatments (Table 11). If decreased weed biomass results in decreased competition and allows for increased flax grain yield, similar grain yields harvested in the weedy control plot and the weed-free herbicide plot is not consistent. The amount of weed biomass harvested in the control plots was 1009.7 lb A^{-1} (Table 11), a significantly greater amount than present in the herbicide plot even though grain yield was similar between the treatments. Additionally in 2006 at Central IA, grain yield was not significantly different among treatments; however weed biomass among the treatments was different. Again in this site-year weed biomass weighed the least in the herbicide treatment (485.7 lb A^{-1}) but ranged from 1301.3 to 2254.8 lb A^{-1} although all treatments yielded similar grain yields (Table 11).

These results do not support or dismiss the results from Project 1 but demonstrate that the link between the negative effects of increased non-flax biomass on flax grain yield is not clear. Further, the exact amount of biomass needed to affect flax grain yield needs to be determined in multiple year investigations with weed-free checks for each treatment.

Oil

The total oil content of the seed was not influenced by the individual treatments or locations. However, year greatly influenced total oil content averaging 38.9% in 2005 and 41.3% in 2006 (Table 13). Oil data was not analyzed for NW IA in 2005.

Fatty acid profile

The fatty acid profile was only analyzed in 2006. Alpha linolenic acid content was significantly higher in Central IA (54.7%) compared to NWIA (52.2%) (Tables 14 and 15). The grass/legume treatment yielded the highest ALA percentage (54.0%). Linoleic acid content was significantly higher at NWIA (12.9%) than Central IA (11.7%) (p=0.0001). No difference in linoleic acid content resulted among the treatments grown in either location. Oleic acid was significantly higher in NWIA (24.5%) compared to Central IA (22.9%) (p=0.0001). The herbicide treatment was significantly higher than the other treatments. Stearic acid was significantly higher in the broadcast (3.4%) and herbicide (3.3%) treatments in NW IA. In Central IA the 2-way, red clover and grass/legume treatments yielded less. Palmitic acid was not affected by the treatments. In comparison with the other fatty acids, ALA was negatively affected by the herbicide treatment, while the other fatty acids responded positively.

Conclusions

At certain levels of non-flax biomass pressure, specifically weeds, flax grain yield will be negatively affected. Controlling weeds during the flax year is not as predictable even when using an herbicide application. However optimal application timing will increase the herbicide's efficacy. Oil content of the seed was influenced more by environmental differences between the years than the application of treatments. Alpha linolenic acid, the most abundant unsaturated fatty acid measured, was lowest in the herbicide treatment. Without knowing the fatty acid profile from 2005 and knowing that high weed biomass was harvested at Central IA in the broadcast treatment this research only suggests that a weedier treatment may increase ALA content. Stearic and oleic acids were higher in the herbicide treatment but not palmitic acid, which is the most saturated fatty acid of these five. Multiple years of field trials and analysis of the fatty acid profile may indicate if under Iowa climate conditions ALA, a highly unsaturated fat, increases in a weedier field.

Literature cited

Albrecht, H., and H. Sommer. 1998. Development of the arable weed seed bank after the change from conventional to integrated and organic farming. Aspects of Applied Biology, Weed seedbanks: determination, dynamics and manipulation 51:279-288.

Albrechtsen, R.S., and C.D. Dybing. 1973. Influence of seeding rate upon seed and oil yield and their components in flax. Crop Sci. 13:277-280.

Alessi, J., and J.F. Power. 1970. Influence of Row Spacing, Irrigation and Weeds on Dryland Flax Yield, Quality, and Water Use. J Am Soc Agron. 62:635-637.

Alex, J. 1968. Competition between linseed flax and *Saponaria vaccaria*. Can J Plant Sci. 48:1968.

Berglund, D., and R. Zollinger. 2002. Flax Production in North Dakota. Extension Publication A-1038. North Dakota State University Extension.

Burrows, V., and P. Olson. 1955. Reaction of small grains to various densities of wild mustard and the results obtained after their removal with 2,4-D or by hand. II Experiments with flax. Can J of Agr Sci. 35:193-201.

Culbertson, J.O., H.W. Johnson, and L.G. Schoenleber, (eds.) 1961. Producing and harvesting seeds of oilseed crops. U.S. Gov't Print Off. 591:1-192-199.

Dillman, A.C., and J.C.J. Brinsmade. 1938. Effect of spacing on the development of the flax plant. J Am Soc Agron. 30:267-278.

Dixit, J.P., S.K. Chourasia, P.V.A. Pillai, and R.A. Khan. 1994. Assessment of flexibility of sowing time of linseed (*Linum usitatissimum* L.*)* varieties under double cropping system in Tawa Command. Indian J Agron. 39:105-109.

Fontana, F., D. Cremaschi, C. Vender, C. Maestrini, and L. Natarelli. 1996. Comparison of two spring sowing dates for linseed (*Linum usitatissimum* L.) cultivars. Rivista di Agronomia 30:248-251.

Friesen, G., and L. Shebeski. 1960. Economic losses caused by weed competition in Manitoba grain fields. I. Weed species, their relative abundance and their effect on crop yields. Can J Plant Sci. 40:457-467.

Friesen, G.H. 1986. Effect of weed interference on yield and quality of flax seed oil. Can J Plant Sci. 66:1037-1040.

Gruenhagen, R., and J. Nalewaja. 1966. Wild buckwheat competition in flax. Meet Weed Soc Amer. 17:380-384.

Gruenhagen, R.D., and J.D. Nalewaja. 1969. Competition between flax and wild buckwheat. Weed Sci. 17:380-384.

Gubbels, G.H. 1978. Interaction of cultivar and seeding rate on various agronomic characteristics of flax. Can J Plant Sci. 58:303-309.

Hassan, F., M. Leitch, and M. Abbasi. 2005. Effects of seeding densities and row spacing on yield and yield components of linseed (*Linum usitatissimum* L.). Acta Agronomica Hungarica 53:309-317.

Klages, K.H. 1932. Spacing in relation to the development of the flax plant. J Am Soc Agron. 24:1-17.

Klebesadel, L., and D. Smith. 1959. Light and Soil Moisture beneath Several Companion Crops as Related to the Establishment of Alfalfa and Red Clover. Botanical Gazette 121:39-46.

Krall, J.L., T.J. Army, A.H. Post, and A.E. Seamans. 1965. A summary of dryland rotations and tillage experiments at Havre, Huntley and Moccasin, Montana. 599. Montana Agr Expt Sta Bull.

Puhr, L.F. 1962. Twenty years of soil management on a Vienna silt loam. 508. South Dakota Agr Expt Sta Bull.

Sarvis, J.T., and J.C. Thysell. 1936. Crop rotation and tillage experiments at the Northern Great Plains Field Station 536. North Dakota USDA Tech Bull., Manden, ND.

Shahidullah, M., U. Islam, M. Karim, and R. Mondol. 1997. Performance of four linseed varieties: at different dates of sowing. J Scientific and Industrial Res. 32:186-190.

Stevenson, F., and A. Wright. 1996. Seeding rate and row spacing affect flax yields and weed interference. Can J Plant Sci. 76:537-544.

Vick, B.A., C.C. Jan, and J.F. Miller. 2004. Second-year study on the inheritance of the reduced saturated fatty acid trait in sunflower seed. Proceedings 26th Sunflower Research Workshop, Fargo, ND.

Table 1. Mean monthly air temperature and rainfall in Central IA in 2005 and 2006. Mean is the average of data from 1951-2007.

	Air Temperature			Rainfall		
Month	2005	2006	Mean	2005	2006	Mean
	---------------------^{o}F † ----------------			----------------- in. ‡ ---------------		
March	38	38	36	1.38	2.93	2.05
April	55	56	50	3.24	4.30	3.51
May	60	62	61	4.38	2.15	4.50
June	74	72	70	4.87	0.81	4.86
July	76	76	74	4.10	5.56	4.02
August	72	72	72	6.76	6.16	4.20
September	69	61	64	4.36	7.51	3.23
October	54	50	52	0.35	2.49	2.33

† Tc = (5/9)x(Tf-32)
‡ cm=in. x 2.54
Information source: NWS CO OP

Table 2. Mean monthly air temperature and rainfall near Calumet, IA in 2005 and 2006. Mean is the average of data from 1951-2007.

	Air Temperature			Rainfall		
Month	2005	2006	Mean	2005	2006	Mean
	-------------------^{o}F † ----------------			------------------ in. ‡ ----------------		
March	34	34	33	0.54	4.32	1.74
April	52	52	48	3.24	3.42	2.67
May	57	61	59	3.41	1.19	3.86
June	71	70	69	9.89	4.21	4.59
July	75	77	73	2.44	0.87	3.67
August	71	72	71	2.71	5.97	3.83
September	67	58	62	4.61	4.06	3.18
October	51	47	50	1.67	0.23	1.79

† Tc = (5/9)x(Tf-32)
‡ cm=in. x 2.54
Information source: NWS CO OP

Table 3. Flax grain yield at 8% moisture, weed biomass and non-flax biomass harvested from all main treatments in 2005 and 2006.

Treatment	Grain Yield		Weed Biomass		Non-Flax Biomass	
	2005	2006	2005	2006	2005	2006
	---------------------------------- lb A^{-1} †	--------------------------------				
Control	1439.7	1097.3	305.7	1373.2	326.1	1373.2
Herbicide	1486.9	1069.0	10.7	616.2	22.1	616.2
Red Clover	1315.1	1008.7	229.8	1331.3	481.8	1601.1
p-value	0.2337	0.3140	0.2011	*	0.0783	*
LSD	-	-	-	*	-	*

† kg ha^{-1}=lb A^{-1}x1.12

* No p-value is reported because the interaction of the main treatments and subplots is significant.

Table 4. Flax grain yield at 8% moisture and non-flax biomass harvested from all subplot treatments in 2005 and 2006.

Treatment	Grain Yield		Non-flax biomass	
	2005	2006	2005	2006
	------------------ lb A^{-1} ------------------			
Unweeded	1452.4	940.1	449.2	2180.8
Weed-free	1375.4	1176.5	104.2	212.9
p-value	0.4977	0.0001	0.0266	*
LSD	-	148.2	201.9	*

† kg ha^{-1}=lb A^{-1}x1.12

*No p-value is reported because the interaction of the main treatments and subplots is significant.

Table 5. Non-flax biomass yield harvested from all treatments in 2005 and 2006.

Treatment	Subplot	2005	2006
		------- lb A^{-1} † ------	
Control	Unweeded	638.9	2620.6 a
Control	Weed-free	13.2	125.9 c
Herbicide	Unweeded	36.9	1181.4 b
Herbicide	Weed-free	7.1	50.9 c
Red Clover	Unweeded	671.5	2740.5 a
Red Clover	Weed-free	292.1	461.8 c
p-value		0.2810	0.0301

† kg ha^{-1}=lb A^{-1}x1.12

Means followed by the same letter were not significantly (p=0.05) different.

Table 6. Weed biomass yield harvested from all treatments 60 days after flax harvest in 2006.

Treatment	Subplot	2006
		lb A^{-1} †
Control	Unweeded	1876.9 c
Control	Weed-free	2932.4 b
Herbicide	Unweeded	2074.9 bc
Herbicide	Weed-free	3873.9 a
Red Clover	Unweeded	1373.2 c
Red Clover	Weed-free	1373.2 c
p-value		0.0235

† kg ha^{-1}=lb A^{-1}x1.12

Means followed by the same letter were not significantly (p=0.05) different.

Table 7. Non-flax, underseeding and weed biomass yield harvested from all main treatments, 60 days after flax harvest in 2006.

Treatment	Non-flax biomass	Underseeding	Weed
	------------------------------	lb A^{-1} †	------------------------------
Control	2404.7	0.0	2404.7
Herbicide	2974.4	0.0	2974.4
Red Clover	3031.3	1658.1	1373.2
p-value	0.2856	0.0001	0.0073
LSD	-	180.3	*

† kg ha^{-1}=lb A^{-1}x1.12

* No p-value is reported because the interaction of the main treatments and subplots is significant.

Table 8. Total oil content of flaxseed at 8% moisture measured in all treatments in 2005 and 2006.

Treatment	Sub-plot	2005	2006
		--------- %	--------
Control	Unweeded	49.2	41.2
Control	Weed-free	49.7	41.1
Herbicide	Unweeded	46.4	41.6
Herbicide	Weed-free	47.9	41.0
Red Clover	Unweeded	49.3	41.6
Red Clover	Weed-free	46.7	41.1
p-value		0.0742	0.6782

Table 9. Fatty acid profile of flaxseed at 8% moisture measured in all main treatments in 2006.

Treatment	ALA (18:3)	Linoleic (18:2)	Oleic (18:1)	Stearic (18:0)	Palmitic (16:0)
	-----------------------------	-----------------------------	%	-----------------------------	-----------------------------
Control	54.3	11.9	23.0	3.3	5.1
Herbicide	53.4	12.2	23.8	3.4	5.2
Red Clover	54.3	11.9	23.2	3.3	5.1
p-value	0.0007	0.0193	0.0054	0.0003	0.2381
LSD	0.20	0.13	0.22	0.02	-

Table 10. ALA (18:3) and oleic (18:1) acid content of flaxseed at 8% moisture measured in all sub-plot treatments in 2006.

Treatment	ALA (18:3)	Oleic (18:1)
	----------------------%	---------------------
Unweeded	54.3	23.1
Weed-free	53.7	23.5
p-value	0.0048	0.0072
LSD	0.25	0.20

Table 11. Weed biomass yield harvested from all treatments from two sites in Iowa in 2005 and 2006.

Treatments	2005		2006	
	Central IA	NWIA	Central IA	NW IA
	---------- lb A^{-1} † ----------			
Control	453.9	887.5	2230.8	1009.7
Broadcast	1822.4	1676.9	1448.8	1703.1
2-way	144.5	1656.3	1870.9	1517.2
Alfalfa	623.3	1237.2	1301.3	995.7
Red Clover	271.1	1367.3	2254.8	1205.3
Grass/Legume	256.1	1122.3	2032.9	1307.3
Herbicide	110.7	686.4	485.7	53.9
p-value	0.0043	0.2641	0.0068	0.0015
LSD	860.4	-	901.4	655.5

† kg ha^{-1}=lb A^{-1}x1.12

Table 12. Flax grain yield at 8% moisture harvested from all treatments from two sites in Iowa in 2005 and 2006.

	2005		2006	
Treatments	Central IA	NWIA	Central IA	NW IA
	------------------ lb A^{-1} † ------------------			
Control	1491.9	1721.6	893.4	1245.6
Broadcast	914.1	1604.3	890.5	1050.2
2-way	1405.9	1695.2	753.3	1152.9
Alfalfa	1518.1	1631.9	817.9	1132.7
Red Clover	1557.6	1451.8	884.9	1031.7
Grass/Legume	1511.6	1570.9	768.2	1126.8
Herbicide	1512.1	1632.9	865.5	1381.7
p-value	0.0052	0.4526	0.7839	0.0003
LSD	329.2	-	-	129.4

† kg ha^{-1}=lb A^{-1}x1.12

Table 13. Total oil content of flaxseed at 8% moisture harvested from all treatments from two sites in Iowa in 2005 and 2006.

	2005	2006	
Treatments	Central IA	Central IA	NW IA
	---------------------------- lb A^{-1} †	---------------------------	
Control	39.2	41.2	41.6
Broadcast	38.5	39.4	42.0
2-way	39.6	41.0	41.1
Alfalfa	39.1	41.3	42.1
Red Clover	39.3	41.0	40.5
Grass/Legume	39.2	40.9	41.8
Herbicide	38.8	43.0	41.5
p-value	0.0005	0.2654	0.4689
LSD	0.44	-	-

† kg ha^{-1}=lb A^{-1}x1.12

Table 14. Fatty acid profile of flaxseed oil from all treatments at Central IA in 2006.

Treatments	Central IA				
	ALA	Linoleic	Oleic	Stearic	Palmitic
	--%				--
Control	54.67	11.62	23.24	3.27	5.21
Broadcast	54.79	11.85	22.66	3.30	5.27
2-way	55.00	11.75	22.32	3.23	5.34
Alfalfa	54.75	11.75	22.64	3.28	5.17
Red Clover	54.75	11.65	22.90	3.25	5.20
Grass/Legume	55.36	11.70	22.50	3.23	5.24
Herbicide	53.51	11.86	23.97	3.35	5.20
p-value	0.0025	0.0915	0.0024	0.0077	0.8582
LSD	0.73	-	0.72	0.06	-

Table 15. Fatty acid profile of flaxseed oil from all treatments in NW IA in 2006.

Treatments	NW IA				
	ALA	Linoleic	Oleic	Stearic	Palmitic
	---------------------------------------%				---
Control	52.36	13.02	24.39	3.26	4.95
Broadcast	51.46	12.84	25.26	3.37	5.02
2-way	52.44	12.78	24.36	3.24	5.14
Alfalfa	52.37	12.89	24.31	3.26	5.00
Red Clover	52.64	13.13	23.88	3.26	5.06
Grass/Legume	52.75	12.93	24.11	3.24	5.12
Herbicide	51.43	13.31	24.92	3.39	5.08
p-value	0.0055	0.0573	0.0459	0.0001	0.1748
LSD	0.75	-	0.85	0.03	-

CHAPTER V

Engaging in Alternative Crop Production: Interviews with Four Flax Farmers in Iowa

Introduction

Over-production of commodity crops has devastated our landscape both environmentally and socially (Comstock, 1987; Goldschmidt, 1998; Thompson, 1995). Human and environmental health has been affected by the increased use of chemicals in the form of pesticides to control various pests of the dual crop agri-production system. Herbicides such as atrazine have been studied and results prove that it persists in our water and is a known endocrine disruptor (NRDC, 2004). The once important fabric of farming communities, modern agriculture, has been drastically reduced (NASS, 2007). Concentration of the industry into the hands of fewer producers who possess larger amounts of financial and built capital than their smaller scaled neighbors has created desperate times in rural America. However, even with increased research of specific crops, increased use of technology and improved efficiencies, the current production system has not reduced the numbers of hungry and food insecure people in the rural and urban United States nor around the world (Lappé et al., 1998).

In reaction to this industrial form of agriculture, some farmers have initiated alternative farming and marketing systems. Alternative farming techniques that incorporate civic values outside the industrial convention are reflected in the increased number of organic acres and the presence of grass-fed, natural and hormone-free products in the grocery store (Fitzgerald, 2005; Greene, 2006). However, this transition to alternative agriculture production has come about slowly due to the considerable new human, social, cultural, political, financial, built and environmental capital needed to change the context in which farmers currently can practice agriculture. To distinguish between farmer's intentions and agency to employ alternative agriculture practices, this study describes four farmer participants in the context of conventions theory and documents what capitals they used to decide to grow a new crop.

Conventions theory initially described by Boltansky and Thevenot (1991) allows a predominantly economic model to be evaluated by new outcomes beyond price and yield. The quality of a product in a market is characterized beyond its monetary value (Sylvander, 1993). In Renard (2003), four conventions: domestic, civic, market and industrial are described.

Trust, respect, partnership, attachment to place and tradition are characteristics of a *domestic* convention. It focuses on the family or farm unit and often social capital is built through interactions with neighbors. A *civic* convention values the benefits to the greater society. It is based on an idea of collective responsibility, fairness and equality. A civic convention's inference is greater than a domestic convention but both have similar objectives: societal benefits. A *market* convention is characterized by its dependence on commercial prices, organizations that buy and sell products and retailers and distributors that bring the product to market. The characteristic of the product is minimized to its profit in the market place. The civic and domestic conventions still function within a market convention but with additional characteristics of the product being traded. For example, who, how and where the product was produced is important. An *industrial* convention depends on formal standards, inspections and certifications of products, efficiency and the reliability that comes with standardization. The industrial convention favors products that focus on their suitability for processing, use by industry buyers and ability to be reduced to individual parts for use by processors and sold by retailers. These four conventions were used to categorize a group of four farmer cooperators who conducted on-farm research with an alternative crop in 2005 (Table 1).

The Community Capitals Framework was chosen to attain reactions to specific questions categorized by the seven capitals: human, social, cultural, environmental, built and financial (Flora, 2004). This tool is currently used to assess strategic interventions and projects by the North Central Regional Center for Rural Development (NCRCRD), which initiates research and outreach projects in rural communities of the north central United States.(NCRCRD, 2006).

Each capital represents a specific piece of the interaction between a person, the surrounding community and the context within which they both exist. *Human* capital is comprised of the skill sets, knowledge and capacities that people possess or attain. *Social* capital is the interaction between citizens and community support organizations, such as non-profits, government agents, industry, educators, lenders and business leaders. Built capital and financial capital were separated into two categories although they are very similar. *Built* capital is the tangible, physical infrastructure and facilities that exist for citizens or communities to increase access to and trade of goods and services. *Financial* capital includes access to credit, income, wages or earnings from the sale of on-farm products such as grain or animals. It can also include off-farm income. *Environmental* capital is also referred to as natural capital and is described as the diversity and stability of the environment which exist on farms or the potential for increased ecosystem diversity and stability. *Cultural* capital is embedded in the values and practices of the farmers and rural inhabitants. *Political* capital is the ability for farmers to have a platform where they can advocate and have a voice. This indicator is distinct from social and cultural capital in that it goes beyond the local community and identifies access to elected officials such as state or federal policymakers or other influential government officials. The capitals framework was employed to analyze and compare each farmer's specific situation. Their responses were categorized by the capital and used to assess how and why these producers carved out a physical and temporal space to produce an alternative crop (Table 2) (NCRCRD, 2006).

In 2005, three certified organic flax producers and one conventional flax producer participated in on-farm flax research trials with Practical Farmers of Iowa (PFI) using support from an ISU Agronomy Endowment grant. After one year of field research, interviews were conducted with the four farmer cooperators. In this paper, we seek to situate the farmers in terms of these four conventions in order to better understand each farmer's use of different capitals from the community capitals framework. Our hypothesis is that regardless of the convention in which a farmer predominantly resides, they will be more likely to adopt a new crop, if they are able to use several capitals.

Methods

At the end of the growing season, farmers were asked if they would participate in an interview to discuss their motivation for conducting on-farm research and alternative crop production. All four farmers were interested. Interviews were conducted during the first week of January when farmers were less occupied with field operations. The interviews were conducted at the homes of three of the farmers and one interview was conducted over the phone. All farmers had access to the following protocol before the interview. This protocol was used to guide the discussion.

Protocol

- Current farming system background
1. How many acres do you farm?
2. What is your crop rotation?
3. Does flax fit into your rotation or did you need to modify the current system?
4. Do you have animals?
5. If yes, how many and what kinds?
6. Do you sell a large portion of your crops off-farm or are they used for feed?
7. What crops specifically are used as animal feed?
8. Did feed bought off-farm change with the addition of flax?
9. Are you feeding flax?
10. Are you happy with how flax fits into your farming system? Did it improve flow or are more changes needed?

- Human capital
11. When was the first time you planted flax?
12. Why did you initially become interested in planting flax?
13. What were challenges to planting an alternative or new crop?
14. What new knowledge was needed to plant flax? Did you rely on any old skills/trade secrets?

- Social capital
15. Did you interact with university extension agents, other farmers, Spectrum/American Natural Soy, PFI or the internet for advice on how to grow flax?
16. If yes which category of person (s) was most helpful and why did you chose their help?

- Built capital
17. Did you own, rent or have access to the machinery needed to plant, windrow and harvest this crop?
18. Did you immediately sell the crop after harvest or did you need to store it for a certain amount of time?
19. Did you possess this storage or have access to storage?
20. Did you possess or have access to trucks to transport the crop to its final destination?

- Environmental capital
21. What environmental benefits or challenges do you see from planting flax?
22. Do you think modification to your current system by adding flax will impact

positively or negatively the farming environment i.e.: soil quality, nutrient level, erosion, compaction or runoff, etc.?

- Cultural capital

23. What do your neighbors think about flax?
24. Have you had conversations with neighbors or townspeople about your farming system or about raising flax?
25. Does this impact the decisions made about your farming system?

- Financial capital

26. What economic benefits or challenges do you see from planting flax?
27. Can you receive a subsidy payment for flax?
28. What crop is flax replacing? How variable are the economics of that crop?

- Political capital

29. What state or local support is needed to help farmers like you continue farming the
way you farm?
30. What national, state or local level policy changes could promote crop diversification?
31. Do you feel you are making a political statement by growing flax?

- Future plans

32. Will you raise flax next year? If yes why? If no, why not?
33. What was the most important reason for growing flax this year?

The interview responses are a summary of several outside interactions and conversations with each farmer. Names have been changed to maintain anonymity. The producers interviewed are Peter located in northwest, Dan in north central, Roger in southwest and Joe in southeastern Iowa. Each individual farm operation varies somewhat, but all farms are diversified, defined as having crops and livestock. Three farms are certified organic while one is described by the farmer as “managed at a reduced chemical level.” Flaxseed was marketed to a variety of buyers; two farmers marketed to Spectrum Organics, a buyer in Iowa; one marketed to a local organic grain buyer for the feed market; and the other to an egg producer who markets his eggs as containing omega-III fatty acid.

Results and discussion

Peter

Peter's farming system includes a wean-to-finish hog operation and two different cropping rotations on farmland that he began transitioning to certified organic production in 2001. All 300 acres were certified in 2005. The three year rotation includes: corn, soybean and a small grain and the four year rotation includes: corn, soybean followed by fall triticale, flax underseeding with red clover and an additional year of red clover. Peter substitutes flax for a small grain in the four year rotation. Hogs are sold on the conventional market, and Peter states he purchases "cheap feed" for them, i.e., he purchases conventional grain from the local grain elevator. All grain grown on the farm is sold at organic prices, except his oats, which "receive a non-organic seed price".

Peter rents all 300 acres from his mother and will inherit 80 acres when the farm is passed onto him and his siblings. He plans to rent the additional 220 acres from his family in the future. Peter farms 15 miles from the current crusher of flaxseed in Iowa. Peter has grown flax since 2004, beginning with an experimental 10 A. This was the first time flax had been grown on more than one acre in Iowa since the 1950s.

Peter employs the market convention in most situations but also adheres to the industrial and civic conventions. Peter decides which crops and livestock to grow based on price (market). Although his production is organic his crops are sold into the organic commodity market to be purchased by animal producers and large scale human food processors. Because of the similarity with conventional production and marketing it could be suggested that he also employs the industrial convention. He grows conventional hogs because his market is 15 miles away and they are cheap to deliver (market). The price premiums for organic or alternatively labeled pork are not profitable to him. However three actions that he engages in suggests that he also adheres to a civic convention, although they were not specifically stated. Peter continually investigates environmentally sound farming practices on his farm and before transitioning to organics began growing herbicide-free soybeans. Although these transition beans “received a price premium [they] were also good for the environment (market and civic).” His actions show his commitment to environmental sustainability and its benefit to society.

Several themes emerged from the interview with Peter. Besides being the first farmer in Iowa to plant flax in over 50 years, Peter continually experiments and “fine-tunes” his farming system through on-farm research. Peter tested herbicide-free soybeans with Pioneer’s “A Better Life Program” for eight years before transitioning to organic production. Peter researched information from the Jefferson Institute in MO, the University of Minnesota, Spectrum Organics, and from ISU Value-Added Agriculture Extension personnel to learn more about flax production. Additionally, Peter spoke with neighboring farmers who had grown flax when they were younger. Many said it was a beautiful crop but was difficult to harvest because of the strength of the straw. He used these “old-timers’ horror stories” about raising flax as motivation to understand and experiment with this mysterious crop. To continually learn and improve his farming system, Peter performs various experiments on his farm.

Peter has one neighbor who also grows organic grains and who planted flax in 2005. Although it was not directly stated, Peter eluded to the comfort of having at least one neighbor that was organic in his area, but sad that only one existed. In the past Peter felt peer pressure to be a ‘good farmer’ in the conventional sense. This was very important when he first started transitioning to organic production; however, he states "now I feel that my income level proves that I am a good farmer." Peter noted that his income from farming organically has allowed him "to play on the farm and discover stuff about the crops" that previously was not feasible with the tight profit margins from growing corn and soybeans. Burton (2004) confirmed that the traditional identity of farmers has been challenged by new production methods in agriculture. This has led to resistance to changing current practices even with incentive programs.

The capitals which encouraged Peter to plant an alternative crop were environmental, built, financial and human (Table 2). Peter repeatedly expressed the importance of a lengthy rotation. This allowed him the flexibility to substitute one of his crops. The human capital Peter employs includes a curious spirit and ability to work with small-seeded crops. His profits from cash grain sold at organic prices and close proximity to his final market located only 15 miles from his farm further secured his rationalization to grow flax. Additionally, because he does not receive an organic comparable price for oats, flax is a more profitable substitute. These capitals together allowed Peter the flexibility to experiment with this alternative crop. Peter will continue to produce flax next year, increasing from 10 to 35 acres.

Don

Don's farming system includes 150 cow-calf pairs and two different cropping rotations on 950 acres. His three year rotation includes: corn, soybean and a small grain and his five year rotation includes small grain/hay, hay, corn, soybean and corn. Don owns 500 acres, rents 100 acres from his mom who is "in favor of changes" to the farming operation and rents another 350 acres from a nearby neighbor. Don's farming operation almost doubled in size when a neighbor asked Don to transition his land to organic production and to farm it long-term.

Don employs primarily a market convention, but also adheres to the industrial and civic conventions. He is focused on price (market) but the other conventions are shown through his farming and marketing. Don works to investigate several different farming practices on his farm, to become more environmentally sustainable (civic) and efficient (industrial). Don chose to grow flax to do on-farm research but did not sell into the human consumption market. His product was sold to a local grain buyer for chicken feed.

Beef from the farm is marketed to local buyers but Don himself does not seek out these markets. His wife is the marketer of these products. He focuses on the production of an animal that will bring a good price (market). Finally, because his row-crops are going into the larger organic commodity market, they need to meet certain requirements, which then influence his on-farm practices. Although it could be debated whether these on-farm practices are more environmentally sustainable than prior conventional practices, Don still needs to satisfy requirements that are set by an industry that is responding to consumer demand that may or may not improve society or influence his local community (industrial).

The current farm size is almost more than Don can manage, stating, “I want to improve the current farm structure and make changes internally to better the system; but because the farms are a far distance apart something always gets missed.” Don employs one full-time farm hand and during the growing season employs extra labor.

Don’s responses reflected his cautionary, introspective manner. He stated that he had been watching organics for a while before transitioning 10 years ago. He was interested in organics during college and read *The New Farm*, an alternative farming publication from the Rodale Press. Don is also a contributing member to PFI for the past 16 years and has participated in 14 on-farm trials. Farming became his focus 10 years ago, when he stopped working at an implement dealer in the nearby town. Don states his, “perception about farming changed when [he] switched to organics.” Don’s human and social capital influenced him to learn more about organic production and transition his farm beginning in 1995.

Don employed social capital to acquire more information about flax production. Don’s wife is employed at the state’s land-grant university and could supply him with information or the necessary contacts to access information “by just yelling over the computer” in their home office. Don also relied on Peter, another flax farmer interviewed, for additional flax production tips.

The capitals which allowed Don to incorporate an alternative crop into his farming system were the interaction of the human and social capitals. Because PFI needed a research location and Don had previously worked with PFI and is a member, he was interested in participating in a research trial on his farm. The environmental and built capitals were shown in his use of a long rotation, which allowed him to substitute flax for a small grain. His system was more flexible because of the built capital of his on-farm storage which allowed him to store the crop until he found a market. In addition, by owning all of the appropriate machinery Don had a greater amount of flexibility to produce the crop. Human and cultural capital also motivated him to make changes on the farm to provide his children with the option to farm when they become older. He stated that “children of tenant farmers rarely continue farming.” This has influenced Don and his wife to structure their farming business to allow both sons, who as of this interview were young, to begin farming with modest acreages. Finally his organic certification and experience with organic farming prompted a local landlord to solicit Don to transition his land to organic production and farm it long-term. Although Don did not want to grow flax in 2006, because he was incorporating recently transitioned land into his rotation, he found five acres to do another on-farm trial. In the 2005 flax year, Don was able to feasibly grow this new crop without a great deal of risk because his system was structured to allow for a variety of crops and a great amount of flexibility. The combination of human, social, environmental, built and cultural capitals played a strong role in Don incorporating flax into his farming system.

Roger

Roger’s farming system includes 90 stock cows and calves totaling over 200 cattle, 500-600 hogs marketed yearly on 600 acres with two different crop rotations. Roger’s six year rotation includes: corn, soybean, corn, small grain (oats, barley, peas or flax), and two years of hay. His three year rotation includes: corn, soybean and a small grain. Roger also has pasture land for cattle grazing. His animals are marketed to Organic Valley, directly off the farm and to several health food stores in Central IA. Roger owns 400 acres and rents 200 from his mom and first cousin. His first cousin was an organic farmer but chose not to continue farming in order to begin working with a year-round farmer’s market.

Roger adheres to a strong civic convention. He also employs a market and domestic convention. Roger is an advocate for sustainable agriculture systems because they improve rural communities and produce healthier food (civic). On his farm Roger and his family work to market their farm-raised products in several places (market). They supply natural food stores in three towns, market off the farm to neighbors (domestic) and also market to a large organic hog and beef buyer in Wisconsin. Although they need to meet industry standards they have found other markets for their products to allow them flexibility (market). In addition, their crop production is mostly to feed the animals but Roger does grow specific varieties of crops to supply smaller, niche markets like white corn for white corn tortillas. Their marketing strategy is diverse but products are not simply raised because of price. Crops and animals need to mutually benefit each other for Roger to incorporate them into his system.

Roger's farmland has been certified organic since 1994, although he had been farming at what he classifies as a "reduced chemical rate" since 1983. In the early 80s, Roger began attending alternative agriculture field days. He was not enthusiastic about organic production, because he felt the organic farming model was only "selling him a pitch" instead of a true alternative to industrial farming. He believes that true alternative farming "farms with the environment". However, after Roger saw alternative farming techniques in practice by a local Iowa farmer, "the rest was history" and he began farming with these organic methods.

Roger approaches "farming scientifically" and participates in many on-farm research trials with PFI. He states that "rotations are important;" Roger views flax as advantageous to his rotation, because he can establish a legume during the flax year of the rotation. He is continually concerned about the "one limiting nutrient to his crops, nitrogen." Even now, with longer rotations and intensive management, he states "my yields are still low." He explained that alternative crop production and soil fertility needed more research to provide more information due to the complex relationship of the composting process, nitrogen availability, soil organic carbon and the weather. His concern about a lack of nitrogen motivates him to continue raising livestock to avoid importing nutrients from expensively priced composted chicken manure. His understanding of the importance of environmental capital and its benefit to the long-term viability of an agro-ecological system is critical to the success of his farming system. The value he places on environmental capital has allowed him the flexibility to incorporate a variety of crops and cropping schemes to benefit from the natural environment.

Of the farmers interviewed, Roger was the most passionate about the political capital he uses to advocate and influence farmers to transition to sustainable farming practices. Roger passionately described his involvement in making alternative agriculture a reality through his work with the Distinguished Fellow of the Leopold Center for Sustainable Agriculture, Fred Kirschenmann. He feels that the federal government needs to have a well thought out plan about the future of agriculture. “Only 2% of land [is in organic production, this] does not solve enough problems.” In his words: “the government needs to decide yes or no to improving rural communities and confronting family farmers’ current vulnerable situation. As a country, some argue that we need to focus on the positives of a capitalist system and influence more diversified ownership in agriculture, less foreign competition, improve food security and significantly improve the environment and human health. This can all be achieved with more locally purchased and organically produced foods.” Roger was the only interviewee to explicitly and passionately talk about politics beyond commonly known facts, such as, conventional farmers’ dependence on the subsidy program. He suggested many ways in which the state and federal government could provide incentives to farmers to use more environmentally sustainable methods and provide healthy food to our communities, while bridging the ever-widening gap between city and rural citizens. When asked if he was making a political statement by growing flax, Roger answered, “Yes, absolutely, we need more diversity, new crops to reduce our dependence on only corn and soybean rotations.”

Roger chose to produce flax in 2005 in order to strengthen political, human and environmental capitals. Because he is interested in influencing policy to support family farmers like himself, he continues to farm in order to prove that alternative crop production is feasible. He works to prove this on small amounts of acreage instead of ‘scaling up’. In addition, Roger understands biology and agriculture’s interaction with the environment. It was important to know why a lengthy rotation not only benefited the land, the rural community and Roger’s pocketbook through organic prices, but also the increase in flexibility which allowed him to substitute some acres of his previous small grain with flax. Finally as is common among farmers, some financial freedom was critical to give him options to “meddle” with his farming system while working to improve it.

Joe

Joe farms 210 acres. At any given time 180 - 190 acres are in pasture or hay and 10 - 20 acres are in soybeans. Joe grazes a 35 head cow-calf herd on this land and sells cattle at 500 lb live weight at a local sale barn. Joe divides his acreage into 3 paddocks, as a semi-intensive rotational grazing system. During the summer, Joe’s hay is custom harvested. Because Joe does not typically grow a small grain, he does not own a windrower. This summer he did not need the use of a windrower because a drought in his part of Iowa allowed him to harvest the flax standing without the use of a windrower. His combine, an Allis-Chalmers all-crop harvester, was very useful at properly cleaning his flaxseed. These older model combines were originally designed to harvest small seeds, in contrast to the design of current corn-belt combines to harvest larger seeded crops, primarily corn and soybeans (Hanna, personal communication, 2006). Joe's farm is not organically certified; therefore excluding him from the organic flaxseed market. He sold his flax to an egg producer 115 miles from his farm. Joe is unsure about raising flax next year, because his market is a far distance, he received a low price for conventionally grown flaxseed (half the price of organic certified seed) and he is concerned about lack of access to a windrower for next year's season.

Joe is primarily concerned with the price he will receive for his farm products, i.e. cattle, soybeans and flax. The market convention is central to Joe's decision-making process followed by the domestic convention. He depends on and uses local marketplaces for the sale of his products (domestic). He chooses new enterprises based on what fits best into his farming system and what will bring him the best price in his local marketplace. Since he has a cow-calf herd he is able to fatten some animals and sell them at the local sale barn. He also sells mature calves to his neighbors (domestic). He works to grow a quality animal that will bring a good price in both of these local markets (market). He marketed his flax to a chicken producer, but due to the distance needed to transport the product, he feels he "broke even". Overall, Joe responds to his neighbors' purchasing habits and interests more than an overall industry standard (domestic).

Beyond the future of Joe's flax production, the capitals he hoped to optimize by growing flax were social, human, built and financial capitals. Joe attends many extension meetings and has now become a member of PFI. When he attended the first farmer recruitment meetings to grow flax in 2005, he was curious about raising the crop and sought out ISU Extension and outreach organizations for more information. He used his social capital to network with knowledgeable people about growing this crop. He had enough knowledge and skills (human capital) to take that production information and apply it to his farming system. Also, his knowledge of seeding small seeded crops and his all-crop combine were important human and built capitals to have in growing this crop. During one of my visits he demonstrated his combine, showing its capacity to harvest all types of crops. This piece of machinery allowed his to provide a clean product to his buyer without additional cleaning. In addition, because Joe is recently retired from working for the railroad, he repeatedly indicated that he had more time and financial ability to grow flax. He was in a position to use financial capital to experiment with this alternative crop. Together these capitals increased Joe's ability to grow this crop and allowed him to come to the conclusion that experimenting with this crop was important. Multiply capitals were in play for him to come to this conclusion.

Conclusions

Regardless of the convention that characterized each farmer, he was more likely to incorporate this alternative crop in his rotation, because it furthered several capitals. All farmers depended on a variety of capitals to allow them a certain amount of flexibility to incorporate this crop into their farming system. This study shows the complicated nature of farming systems and a farmer's decision-making process. It may not be simply that industrial agriculture has created a system from which it is difficult for farmers to change their production practices. Rather farmers need to be able to validate a new practice similarly. Supporting NGOs, university extension, farmer organizations, etc.

need to redefine human capital for specific situations and encourage more farmer-to-farmer interactions to increase cultural and social capital. Industrial agriculture may have created a farming system to meet the needs of industry over the needs of the farmer but if a new production practice can satisfy several capitals then farmers will be more willing to incorporate it into their systems (Table 3).

Future

To improve support for farmers incorporating alternative crops into their cropping rotations, PFI, Iowa State University Value-Added Extension and most flax farmers in Iowa created a working group to provide all stakeholders a venue to discuss marketing options, production techniques and troubleshooting for on-farm problems. This network served to strengthen stakeholder participation in the production and sale of alternative crops in the future. In addition to increased social capital, the cultural capital of these farmers increased through interaction with each other and knowledge of other farmers participating in similar farming practices. Continual reverberation of these alternative farming methods has authenticated their value as a productive practice. Darnhofer et al. (2005) showed that organic farming must be considered feasible before a farmer will seriously consider it. If new practices can satisfy several factors in a farmer's decision-making then it will be considered more feasible.

Literature cited

Boltansky, L. and L. Thévenot. 1991. De la justification. Les economies de la grandeur. Nrf essais, Gallimard.

Burton, R. 2004. Seeing through the 'good farmer's' eyes: towards developing an understanding of the social symbolic value of 'productivist' behaviour. Sociologia Ruralis 44:195-215.

Comstock, G. 1987. Is there a moral obligation to save the family farm? Iowa State University Press.

Darnhofer, I., W. Schneeberger, and B. Freyer. 2005. Converting or not converting to organic farming in Austria: Farmer types and their rationale. Agriculture and Human Values 22:39-52.

Fitzgerald, A. 2005. Organic's popularity outpaces production: There's room for meat, dairy and grain farmers to convert, but barriers slow growth. Des Moines Register.

Flora, Cornelia. 2004 Rural communities: legacy and change. Boulder Westview Press, 2004.

Goldschmidt, W. 1998. Conclusion: The urbanization of rural America. Pigs, Profits, and Rural Communities:183–198.

Greene, C. 2006. Organic Production 1999-2003. Economic Research Service. Accessed online on 04/20/2008 at http://www.ers.usda.gov/Data/Organic/

Lappé, Frances Moore, Joseph Collins, Peter Roseet, Luis Esparza., 1998 World hunger: twelve myths. 2nd Edition New York: Grove Press.

National Agriculture Statistics Service (NASS). 2007. U.S. & All States Data - Farm Numbers - Total Farms, Land in Farms, Average Farm Size. Accessed online on 11/16/2007 at http://www.nass.usda.gov/Statistics_by_Subject/Demographics/index.asp.

Natural Resources Defense Council (NRDC). EPA Won't Restrict Toxic Herbicide Atrazine, Despite Health Threat: White House documents obtained by NRDC reveal that industry influenced the decision. Accessed online on 11/16/2007 at http://www.nrdc.org/health/pesticides/natrazine.asp.

North Central Regional Center for Rural Development (NCRCRD). 2006. Community capitals handout. Accessed online on 11/16/2007 at http://www.ncrcrd.iastate.edu/projects/commcap/7-capitalshandout.pdf.

Renard, Marie-Christine. 2003. Fair trade: quality, market and conventions. Journal of Rural Studies. 19:87-96.

Sylvander, B. 1994. La qualité: du consommateur final au producteur (la construction sociale de la qualité: des produits aux facons de produire). Etudes, Recherches en Systèmes Agraires et Développement, INRA. 28:27-49.

Thompson, P. 1995. The spirit of the soil. Routledge London.

Table 1. Description of four conventions: domestic, civic, market and industrial.

Convention	Description
Domestic	Face-to-face relationships; attachment to place; trust, family or farm unit
Civic	Societal benefits; collective principles; fairness
Market	Price; market coordination
Industrial	Standardization; testing procedures; norms

Table 2. Description of the seven community capitals.

Capital	Description
Human	Skills sets; knowledge; human capacity
Social	Interactions: people-people; people-institutions; people-businesses
Built	Infrastructure; facilities
Financial	Income; credit; monetary capital
Environmental	Ecosystem diversity; natural stability
Cultural	Values; practices
Political	Ability to advocate

Table 3. Description of the conventions in which each farmer is situated and the capitals used.

Farmer	Convention	Capital
Peter	Market, industrial, civic	Environmental, built, financial, human
Dan	Market, industrial, civic	Social, human, environmental, built, financial, cultural
Roger	Civic, market, domestic	Political, human, environmental
Joe	Market, domestic	Social, human, financial

Chapter VI

Planting rate effect on flax production

Introduction

The effect of flax planting rate on flax grain yield has primarily been assessed using herbicide applications as the weed control method (Wall, 1994; Stevenson and Wright, 1996). In Manitoba, flax grain yield response was compared among five planting rates, two planting depths and a pre-emergent dinitroanaline herbicide application. In 1992, the first year of the study, an increase in seeding rate from 15 to 30 kg ha^{-1} (13.6 and 27.3 lb A^{-1}) resulted in a higher grain yield response as opposed to a rate increase from 30 to 90 kg ha^{-1} (27.3 and 81.8 lb A^{-1}). No significant herbicide effect was measured. Greater precipitation in 1993 increased the herbicide effect. The interaction of planting rate and herbicide effect was significant. In the herbicide treated plots, planting rate had no effect on flax grain yield, while in the untreated plots, flax yields decreased as planting rate increased. Populations were higher in the untreated plots resulting in greater disease incidence and lodging. Of the combined treatment means, a shallow planting (3 cm, 1.2 in.) increased flax populations. At both planting depths, 3 cm (1.2 in.) and 6 cm (2.4 in.), a higher planting rate increased flax population density (Wall, 1994). Unfortunately, weed biomass weights were not reported for any of the treatments, so comparisons with harvested biomass from this research study cannot be made. Under dry conditions, herbicide effect may not provide sufficient weed control as compared to other cultural practices.

A study conducted in Saskatchewan, Canada compared four levels of post-emergence weed control: no control, broadleaf control, grass control and broadleaf and grass control concomitantly with three planting rates of flax. Control of broadleaf and grass weeds resulted in the highest grain yield. In addition, for every 100 seeds m^{-2} (1075 seeds ft^{-2}) increase in flax planting rate, broadleaf and grass weed yields decreased by 50 kg ha^{-1} (44.5 lb A^{-1}) and 23 kg ha^{-1} (20.5 lb A^{-1}), respectively. In all four levels of weed control, flax grain yield responded positively to a higher flax planting rate (Stevenson and Wright, 1996).

For farmers growing flax who practice organic methods or who want to decrease their use of chemicals, alternatives to herbicides are a must. Viable weed management strategies, such as a varied planting rate, are important due to the potential long-term effects of weeds on these low-input systems. Albrecht and Sommer (1998) measured an average increase from 4050 to 17320 weed seed m^{-2} (377 to 1611 weed seed ft^{-2}) in the soil seedbank three years after conversion from a conventional to an organic production system in the UK. The performance of future crops planted on flax fields could be affected if weeds are not managed during the flax year.

A planting rate study was conducted in 2005 and 2006 at NW IA to determine how grain yield and percent oil are affected by different planting rates. In 2006, the fatty acid profile and weed biomass were also measured to determine if planting rate can be used as a weed management strategy for organic production of flax. We hypothesized that 1) flax grain yield, straw yield, total oil content, ALA percentage and the fatty acid profile would be positively affected by a planting rate of 56 kg ha^{-1} (50 lb A^{-1}) compared to 28 kg ha^{-1} (25 lb A^{-1}) and 84 kg ha^{-1} (75 lb A^{-1}) and 2) weed biomass will not respond differently to various planting rates.

Materials and methods

Description of location

Research experiments were conducted at the ISU Northwest Research and Demonstration Farm near Sutherland, IA (NW IA) (42.9^{o} N, 95.5^{o} W, elevation 445 m, (1461 feet), on a Primghar silty clay loam (fine-silty, mixed, mesic Aquic Hapludolls) soil. At NW IA, soil test results for both years measured a soil pH of 5.9, phosphorus (Bray P_1) level of 21 ppm, potassium level of 152 ppm and organic matter content of 3.8%.

Seedbed preparation

The specific soil conditions in each year determined the primary and secondary tillage used in the spring. At NW IA, in 2005 and 2006, experimental areas were initially disked. In both years, 60 kg ha^{-1} (53 lb A^{-1}) of nitrogen was applied as urea.

Treatments

The study was replicated four times in a randomized complete block design with planting rate as the main plot. All plots were 2.1 m x 7.6 m (7 ft x 25 ft). Flax was drilled with a 2.4 m (8 ft) wide Massey Ferguson wide end-wheel drill with single disk openers and 0.179 m (7 in.) row spacing. Flax (cultivar, ‘Norlin’) was planted at 28 kg ha^{-1} (25 lb A^{-1}), 56 kg ha^{-1} (50 lb A^{-1}), or 84 kg ha^{-1} (75 lb A^{-1}). No herbicide was applied for weed management.

Flax cultivar ‘Norlin’ was planted on 8 April 2005 and 11 April 2006. Planting dates were based on the local planting date for small grain crops. In Iowa, the majority of small grains were planted before 10 April in 2005 and 23 April in 2006 (M. Smith, personal comm., 2006). Flax experiments were planted on land previously seeded to soybeans and weeds had been managed using chemical herbicides. A minimum amount of soybean residue was observed.

Monthly averages of the precipitation and temperature values were measured for each site. Temperature values for each individual growing season were measured (Table 1).

Data collection

Flax was harvested when plants were physiologically mature and 90% of the bolls were a dark brown color as recommended by Berglund and Zollinger, (2002). Flax was harvested on 28 July 2005 and 20 July 2006. Four quadrates (1 ft^2) were randomly placed on the ground encompassing two rows and two interrows of planted flax. Pruning shears were used to cut flax plants at the height of the quadrant 0.0245 m (1 in.). Immediately after harvest, weeds and treatment biomass underseeding were separated from flax plants. In 2005, these fractions were discarded; but in 2006, all material was collected. Flax was placed in cloth bags in dryers at ambient air temperature for three days. All other fractions were placed in paper bags and dried at 60 C (140 F) for seven days. Treatment and weed biomass were weighed to determine total dry matter (DM) yield for each fraction. After flax was air dried in 2005, it was hand threshed; in 2006, it was machine threshed using an Almaco small bundle thresher. Quadrates from individual plots were combined and flaxseed was cleaned using a South Dakota seed cleaner in 2005 and a Westrup LA-LS laboratory air-screen cleaner in 2006. Cleaned samples had less than 0.5% foreign matter (FM). Percent moisture of the seed was measured using the ISO standard procedure for flax grain moisture. One gram (0.035 oz) of flaxseed was baked at 103 C (217.4 F) for three hours to measure the grain moisture (V. Barthet, personal comm., 2006). After threshing, the straw was dried at 60 C (140 F) for five days and weighed.

The total oil content of flaxseed was non-destructively analyzed using a Newport 4000 Nuclear Magnetic Resonance Analyzer from Oxford Analytical Instruments Limited. A 40 ml (1.4 oz) sample was used.

Gas chromatography (GC) was used to determine the fatty acid profile of the oil content. Fatty acid composition is expressed as the percent by weight of the C16 to C24 saturated fatty acids divided by the weight of all fatty acids (Vick et al., 2004). A whole or half flaxseed was placed in a GC autosampler vial and crushed with a thin (end-flattened) glass rod. A 1.0 – 1.5 ml (0.03 – 0.05 oz) of a hexane-chloroform-0.5 M sodium methoxide in methanol (75:20:5, v/v) solution was added to the vial. The sample was injected into a Hewlett-Packard 589-gas chromatograph containing a DB-23 capillary column (30 m x 0.25 mm, J&W Scientific), which was held at 190 C (374 F) for five minutes, then increased to 220 C (428 F) at 10 C minute^{-1} (50 F minute^{-1}). The sample was held at 220 C (428 F) for one minute, then increased to 240 C (464 F) at 20 C minute^{-1} (68 F minute^{-1}), and finally held at 240 C (464 F) for one and a half minutes. The total run time was 11.5 minutes.

Statistical analysis

Statistical analysis was performed using the least square means for the MIXED model procedure of the Statistical Analysis System (SAS). Regression analysis was conducted of each parameter. If the interaction in the MIXED model was significant, individual regression analysis was conducted by year. Linear models are reported on each graph.

Results and discussion

Flax grain yield increased from 1325.80 to 1450.23 lb A^{-1} in 2005, and 1064.26 to 1258.54 lb A^{-1} in 2006, with a higher planting rate. The slope of the line was significantly different from zero (Fig. 1 and Table 2). Straw yield and oil content positively responded to a higher planting rate, however, the interaction of rate and year was significant (Table 3). Regression analysis was performed by year. For straw yield in 2005 and 2006, the slope of the line was significantly different than zero (Fig. 2). For oil in 2005 the slope of the line was not significantly different than zero. The slope of the line in 2006 was significantly different from zero (Fig. 3).

In 2006 weed biomass responded negatively to planting rate as the plant density increased the weed biomass decreased (Fig. 4). The slope of the line was significantly different from zero (Table 5). All fatty acids, except palmitic, were affected by the planting rate treatment (Table 6). The slopes of the lines of ALA and linoleic were significantly different from zero. ALA and linoleic percentage of the total oil content increased with a higher seeding rate (Fig. 5). The slopes of the lines for oleic, stearic and palmitic was not significantly different from zero (Table 6).

Based on this limited data set, grain yield, straw yield, oil content in 2006, ALA and linoleic percentage of the total oil content responded positively to an increased seeding rate. Weed biomass negatively responded. No response was observed in the oil content in 2005 nor oleic, stearic and palmitic fatty acids.

Conclusion

These results suggest that an increased flax planting rate decreased weed pressure in 2006. Additionally, after consulting with flax experts in Canada little known information has been published regarding field treatments’ effect on the fatty acid profile.

Friesen's (1986) study is evidence that more competition between plants, i.e. a greater seeding rate, could decrease the iodine value, the amount of unsaturated fat. In his study, the iodine value decreased from 180 to 175 on average in 25 experiments under weedier conditions. However the above results from this planting rate study are not has obvious.

Flax grain yield, oil content and oil quality characteristics like ALA and linoleic were the greatest in the highest planting rate treatment which corresponded with decreased weed biomass content in 2006. Further research should assess competition's effect on the fatty acid profile and how the micro-climate of a weedy versus non-weedy field affects these results.

Literature cited

Albrecht, H., and H. Sommer. 1998. Development of the arable weed seed bank after the change from conventional to integrated and organic farming. Aspects of Applied Biology, Weed seedbanks: determination, dynamics and manipulation. 51:279-288.

Berglund, D., and R. Zollinger. 2002. Flax production in North Dakota. Extension Publication A-1038. North Dakota State University Extension.

Friesen, G.H. 1986. Effect of weed interference on yield and quality of flax seed oil. Can J Plant Sci. 66:1037-1040.

Stevenson, F., and A. Wright. 1996. Seeding rate and row spacing affect flax yields and weed interference. Can J Plant Sci. 76:537-544.

Vick, B.A., C.C. Jan, and J.F. Miller. 2004. Second-year study on the inheritance of the reduced saturated fatty acid trait in sunflower seed. Proceedings 26th Sunflower Research Workshop, Fargo, ND.

Wall, D.A. 1994. Response of flax and lentil to seeding rates, depths and spring application of dinitroanaline herbicides. Can J Plant Sci. 74:875-882.

Table 1. Mean monthly air temperature and rainfall near Calumet, IA. Mean is the average of data from 1951-2007.

	Air Temperature			Rainfall		
Month	2005	2006	Mean	2005	2006	Mean
	------------------- ^{o}F † ----------------			------------------ in. ‡----------------		
March	34	34	33	0.54	4.32	1.74
April	52	52	48	3.24	3.42	2.67
May	57	61	59	3.41	1.19	3.86
June	71	70	69	9.89	4.21	4.59
July	75	77	73	2.44	0.87	3.67
August	71	72	71	2.71	5.97	3.83
September	67	58	62	4.61	4.06	3.18
October	51	47	50	1.67	0.23	1.79

† Tc = (5/9)x(Tf-32)
‡ cm=in. x 2.54
Information source: NWS CO OP

Table 2. Flax grain yield at 8% moisture harvested from all treatments in 2005 and 2006.

Planting Rate	2005	2006
	-------lb A^{-1} †-----	
25	1325.8	1064.3
50	1336.7	1393.6
75	1450.2	1258.5
p-value: Rate	0.1165	
p-value: Regression	0.2797	

† kg ha^{-1}=lb A^{-1}x1.12

Table 3. Straw yield and oil content measured in all treatments in 2005 and 2006.

Planting Rate	2005	2006	2005	2006
	-------lb A^{-1} †-----		---------% --------	
25	2934.5	941.5	38.5	41.7
50	2788.2	1253.3	38.8	41.7
75	3369.1	1181.4	39.1	41.9
p-values: Year x rate interaction	0.0001		0.0001	
p-value: Rate	0.4584	0.0169	0.2864	0.6142
p-value: Regression	0.4890	0.4748	0.0157	0.2485

† kg ha^{-1}=lb A^{-1}x1.12

Table 5. Weed biomass yield harvested from all treatments in 2006.

Planting Rate	2006
	lb A^{-1} †
25	3136.3
50	1709.1
75	1517.2
p-value: Rate	0.0780
p-value: Regression	0.2641

† kg ha^{-1}=lb A^{-1}x1.12

Table 6. Fatty acid profile of flaxseed oil at 8% moisture harvested from all treatments in 2006.

Planting Rate	ALA (18:3)	Linoleic (18:2)	Oleic (18:1)	Stearic (18:0)	Palmitic (16:0)
	----------------------------	----------------------------	%	---------------------------	---------------------------
25	50.4	11.8	27.4	3.4	5.2
50	51.9	12.5	25.2	3.3	5.0
75	52.1	12.6	24.9	3.3	5.1
p-value: Rate	0.0118	0.0040	0.0024	0.0075	0.1837
p-value: Regression	0.2536	0.2579	0.0261	0.0001	0.0147

Fig. 1. Planting rate effect on flax grain yield in NW IA in 2005 and 2006.

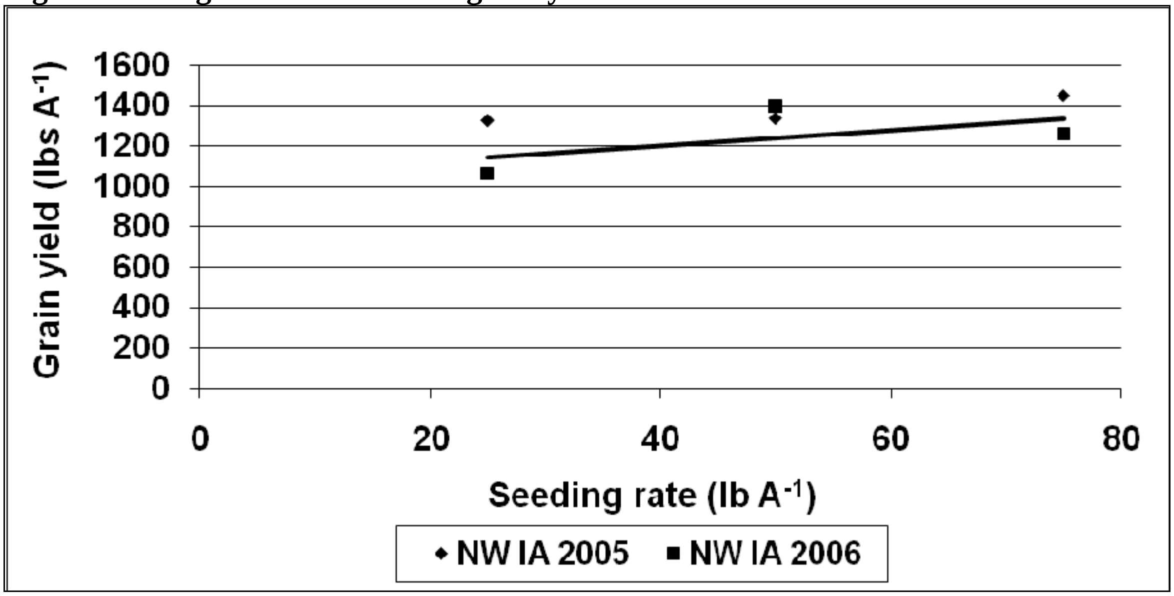


Fig. 2. Planting rate effect on flax straw yield in NW IA in 2005 and 2006.

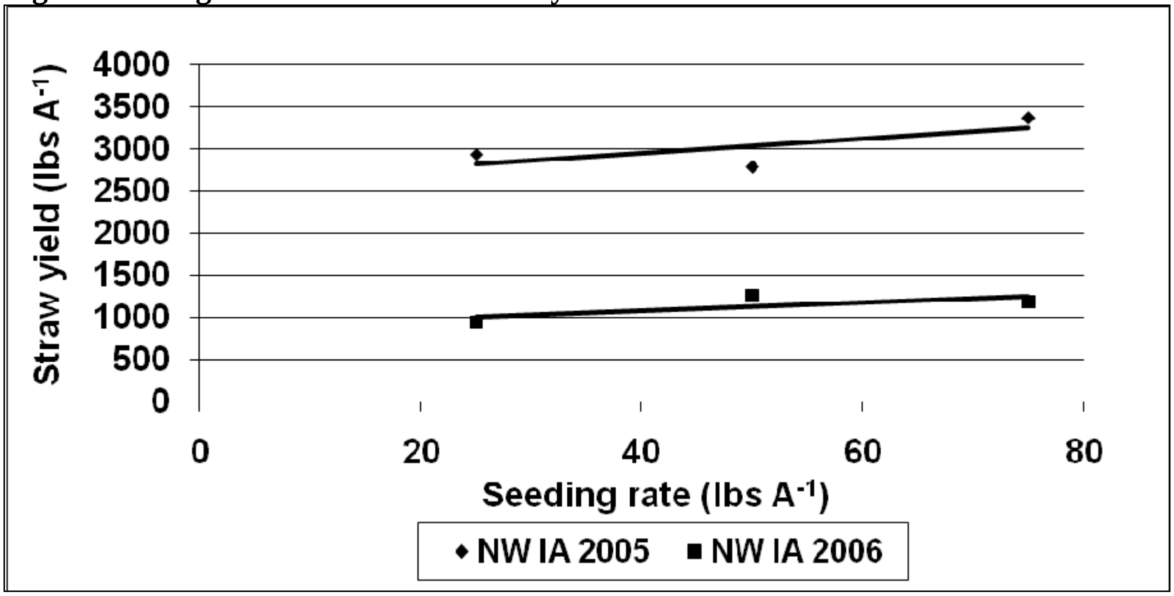


Fig. 3. Planting rate effect on total oil content of flaxseed in NW IA in 2005 and 2006.

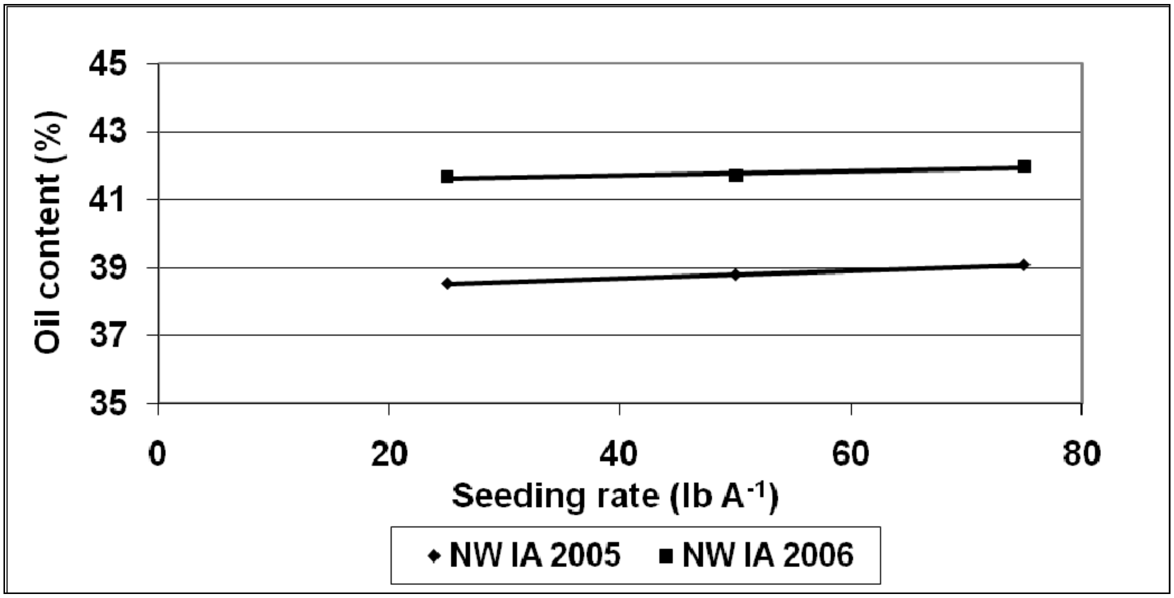


Fig.4. Planting rate effect on weed biomass growth in NW IA in 2006.

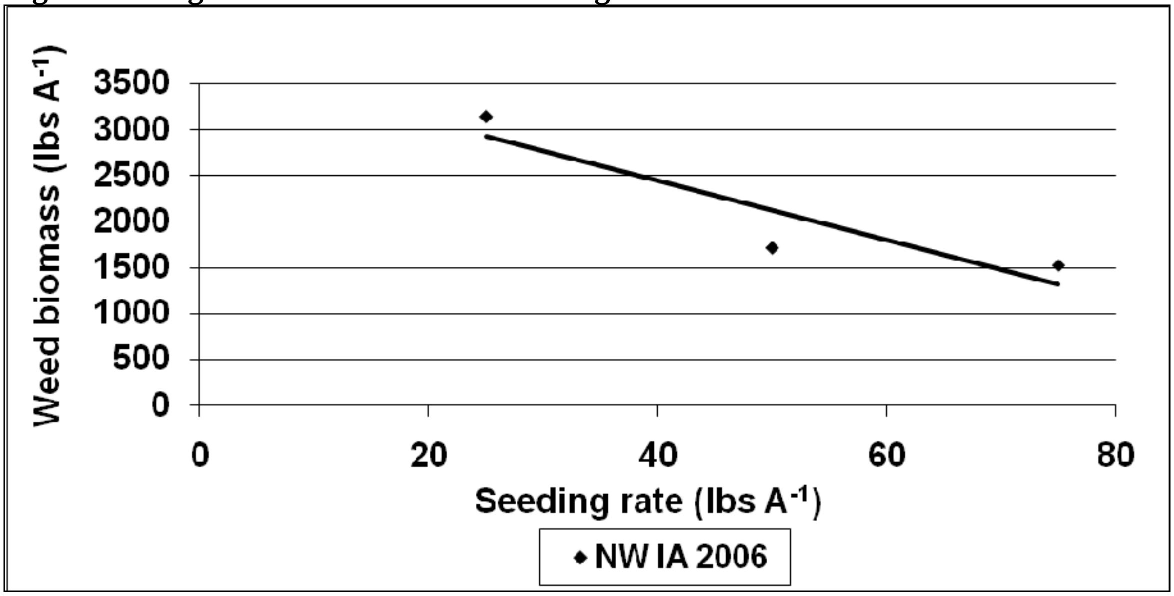
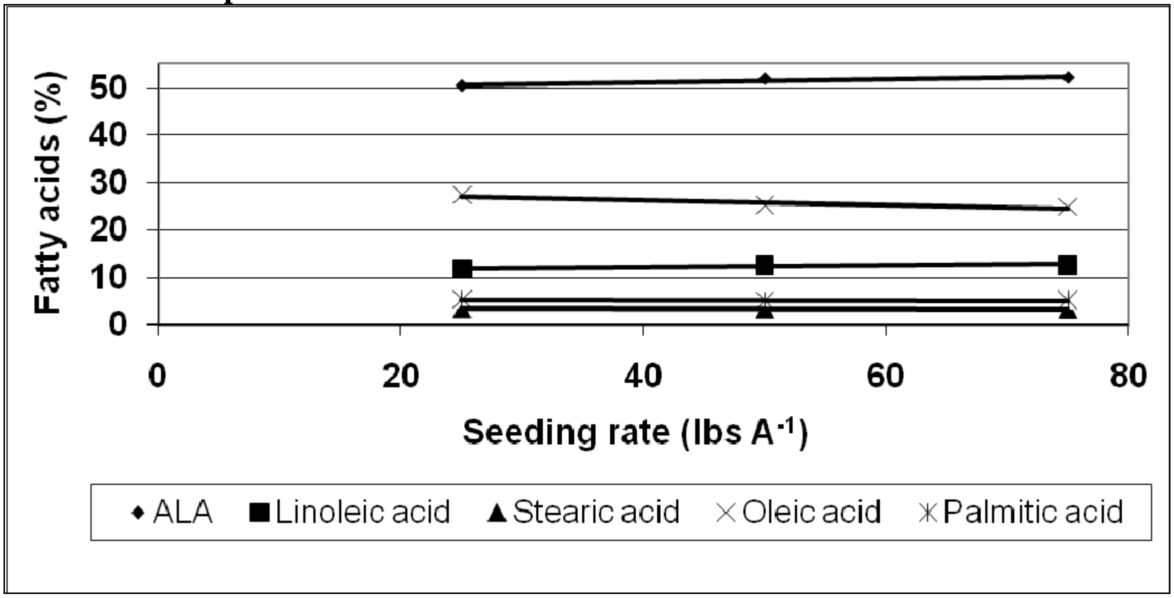


Fig. 5. Planting rate effect on alpha linolenic acid, linoleic acid, oleic acid, stearic acid and palmitic acid in NW IA in 2005 and 2006.



CHAPTER VII

On-farm field experiments

Introduction

Weed competition in any farming system, but especially for low-input production systems, cannot only affect future crops through increased number of weed seeds but also through decreased yields. For farmers who practice organic methods or who want to decrease their use of chemicals and grow flax, alternatives to herbicides are a must. Viable weed management strategies for flax production are important due to the potential long-term effects of weeds on these low external input systems. Albrecht and Sommer (1998) measured an average increase from 4050 to 17,320 weed seeds m^{-2} (377 to 1611 weed seeds ft^{-2}) of total weed seeds in the soil seedbank three years after conversion from a conventional to an organic production system in the UK. The performance of future crops planted on flax fields could be affected if weeds are not managed during the flax year.

To combat weeds during the flax year, farmers can use cultural practices such as delayed planting and pre-seeding tillage to control early germinating weeds (Berglund and Zollinger, 2002); however a delayed planting can decrease flax grain yield (Dixit et al., 1994; Fontana et al., 1996; Shahidullah et al., 1997). Other strategies are varying crop rotation and tillage methods (Sarvis and Thysell, 1936; Puhr, 1962; Krall et al., 1965); decreasing row spacing (Klages, 1932; Dillman and Brinsmade, 1938; Alessi and Power, 1970); varying seeding rate (Albrechtsen and Dybing, 1973; Gubbels, 1978); varying seeding rate and row spacing (Hassan et al., 2005); intercropping flax with a legume

(Klebesadel and Smith, 1959) and varying rates of nutrient application (Culbertson et al., 1961).

These studies used various cultural practices to control weeds during the flax year to determine the resulting flax grain yields with weed biomass production or weed stand counts. The majority of these studies do not describe how weeds were managed. One study did compare hand-weeded and weedy plots (Alessi, 1970). If an herbicide was applied to control weeds in any of these studies, then an accurate evaluation of the cultural treatment's performance was not assessed. Ideally, splitting the experimental plots and hand-weeding half the plot accurately assesses the performance of the weed management strategy.

To create appropriate production guidelines for organic flax grown in Iowa, two biological weed management strategies were analyzed to determine their effect on grain yield, total oil content, the fatty acid profile (alpha linolenic acid, linoleic, oleic, stearic and palmitic), underseeding growth and weed biomass harvested during the flax season and 60 days following flax harvest. Field experiments were conducted on working farms with large scale equipment. Six farms are certified organic farms and one was managed conventionally. All treatments were managed organically during the field trials.

Materials and methods

Description of locations

Research was conducted in 2005 and 2006 at seven locations in Iowa. Two farmers cooperated in both years of the study, resulting in a total of nine site-years. In 2005, research was conducted on farms located near Harlan, IA in Shelby County (SW); Mount Pleasant, IA located in Henry County (SE); Sutherland, IA in Cherokee County

(NW) and Hampton, IA in Franklin County (NC). In 2006, research was conducted on farms located again near Sutherland, IA (NW) and Hampton, IA (NC) and new farm sites in three new locations: Carroll, IA in Carroll County (WC), Tama, IA in Tama County (EC) and St. Charles, IA in Winterset County (SC).

Each farmer recorded planting date, previous year's crop, flax cultivar planted, seedbed preparation, planting rate and predominant weed species (Table 1). Specific soil conditions in each year at each location determined the primary and secondary tillage used in the spring. Equipment availability determined what tillage would be done.

Treatments

All experiments were replicated six times in a randomized complete block design with treatments as the main plots.

The main effect treatments are described as:

- drilled flax, no underseeding (control)
- drilled flax + broadcasted red clover 16 kg ha^{-1} (14 lb A^{-1}) (red clover)
- drilled flax + broadcasted alfalfa 14 kg ha^{-1} (12 lb A^{-1}) (alfalfa)

Flax planting dates were based on the local planting dates for small grain crops (Table 1). In Central IA and NW IA, the majority of small grains were planted before 10 April in 2005 and 23 April in 2006 (M. Smith, personal comm., 2006).

Monthly averages of the precipitation and temperature values were measured for each site (Tables 2 - 8).

Data Collection

Flax was harvested when plants were physiologically mature and 90% of the bolls were a dark brown color as suggested by Berglund and Zollinger (2002). Four quadrates

(1 ft^2) were randomly placed on the ground encompassing two rows and two interrows of planted flax. Pruning shears were used to cut flax plants at the height of the quadrant 0.0245 m (1 in.). Immediately after harvest, weeds and underseeding biomass were separated from flax plants. Flax plants were placed into cloth bags and dried at ambient air temperature for three days. All other fractions were placed in paper bags and dried at 60 C (140 F) for seven days. Underseeding and weed biomass were weighed to determine total dry matter yield for each fraction. After the flax was air dried in 2005, it was hand threshed; in 2006, it was machine threshed using an Almaco small bundle thresher. Following threshing, seed from the four quadrates were combined and flaxseed was cleaned using a South Dakota seed cleaner in 2005 and a Westrup LA-LS laboratory air-screen cleaner in 2006. Cleaned samples had less than 0.5% foreign matter (FM). Percent moisture of the seed was measured using the ISO standard procedure for flax grain moisture. One gram of flaxseed was baked at 103 C (217.4 F) for three hours to measure the grain moisture (V. Barthet, personal comm., 2006). After threshing, the straw was dried at 60 C (140 F) for five days and weighed.

The total oil content of flaxseed was non-destructively analyzed using a Newport 4000 Nuclear Magnetic Resonance Analyzer from Oxford Analytical Instruments Limited. A 40 ml (1.4 oz) sample was used.

Gas chromatography (GC) was used to determine the fatty acid profile of the oil content. Fatty acid composition is expressed as the percent by weight of the C16 to C24 saturated fatty acids divided by the weight of all fatty acids (Vick et al., 2004). A whole or half flaxseed was placed in a GC autosampler vial and crushed with a thin (end-flattened) glass rod. A 1.0 – 1.5 ml (0.03 – 0.05 oz) of a hexane-chloroform-0.5 M sodium methoxide in methanol (75:20:5, v/v) solution was added to the vial. The sample was injected into a Hewlett-Packard 589-gas chromatograph containing a DB-23 capillary column (30 m x 0.25 mm, J&W Scientific), which was held at 190 C (374 F) for five minutes, then increased to 220 C (428 F) at 10 C minute^{-1} (50 F minute^{-1}). The sample was held at 220 C (428 F) for one minute, then increased to 240 C (464 F) at 20 C minute^{-1} (68 F minute^{-1}), and finally held at 240 C (464 F) for one and a half minutes. The total run time was 11.5 minutes.

Statistical analysis

Statistical analysis was conducted at the site-year level to assess how the individual parameters responded to the various treatments. The site-year is the data from each location in each year. Only two farmers replicated their investigations in both years. It was difficult to distinguish the effect of year or location on the measured parameters therefore analysis was conducted at the site-year level. Statistical analysis was performed using the least square means for the MIXED model procedure of the Statistical Analysis System (SAS). Tests of differences among lsmeans were made at the 0.05 probability level and different treatment means were compared using pdiffs.

Results and discussion

Grain yield was statistically different among the three treatments when averaged across all nine site-years (Table 9). The control treatment yielded the greatest grain yield (1564.5 lb A^{-1}). It appeared that grain yields were reduced when the flax was underseeded with a legume. Total biomass, the combination of weed and underseeding biomass harvested from each plot, was only different among site-years but not treatments (Table

10). However, 60 days following flax harvest, weed growth in the control plot was twice as much as compared to the underseeding treatments (Table 11).

Of the biomass harvested 60 days after flax harvest, the red clover underseeding yielded substantially more biomass than the alfalfa, but not statistically significant. Both treatments competed similarly with late summer weed growth. The control had statistically more weeds than the red clover or alfalfa treatments, as would be expected.

Total oil content of the seed was similar among treatments (Table 12); however, seed quality characteristics did vary. Of the fatty acid profile ALA, oleic and stearic acids were not affected by the underseeding treatments (Table 13). Palmitic and linoleic acids were significantly higher in the alfalfa treatment.

Conclusions

Effective weed management strategies for organic farmers producing flax are imperative to maintain the competitiveness of future crops. Because flax is not a competitive crop, weeds will proliferate. Weed growth can be detrimental to future crop production through addition of weed seeds to the soil seedbank. This research shows that establishing an underseeding like alfalfa or red clover with flax will greatly decrease weed production following harvest. However during the flax season, grain yield will be negatively affected by competition from biomass whether it is a weed or an underseeding. Further research with weedy and weed-free treatments will be needed to discover how biomass competes with flax and influences its grain yield.

Literature cited

Albrecht, H., and H. Sommer. 1998. Development of the arable weed seed bank after the change from conventional to integrated and organic farming. Aspects of Applied Biology 51, Weed seedbanks: determination, dynamics and manipulation: 279-288.

Albrechtsen, R.S., and C.D. Dybing. 1973. Influence of seeding rate upon seed and oil yield and their components in flax. Crop Sci. 13:277-280.

Alessi, J., and J.F. Power. 1970. Influence of row spacing, irrigation and weeds on dryland flax yield, quality, and water use. J Am Soc Agron. 62:635-637.

Berglund, D., and R. Zollinger. 2002. Flax production in North Dakota. Extension Publication A-1038. North Dakota State University Extension.

Culbertson, J.O., H.W. Johnson, and L.G. Schoenleber, (eds.) 1961. Producing and harvesting seeds of oilseed crops., Vol. 591, pp. 1-192-199. U.S. Gov't Print Off.

Dillman, A.C., and J.C.J. Brinsmade. 1938. Effect of spacing on the development of the flax plant. J Am Soc Agron. 30:267-278.

Dixit, J.P., S.K. Chourasia, P.V.A. Pillai, and R.A. Khan. 1994. Assessment of flexibility of sowing time of linseed (*Linum usitatissimum)* varieties under double cropping system in Tawa Command. Indian J Agron. 39:105-109.

Fontana, F., D. Cremaschi, C. Vender, C. Maestrini, and L. Natarelli. 1996. Comparison of two spring sowing dates for linseed (*Linum usitatissimum* L.) cultivars. Rivista di Agronomia 30:248-251.896.

Gubbels, G.H. 1978. Interaction of cultivar and seeding rate on various agronomic characteristics of flax. Can J Plant Sci. 58:303-309.

Hassan, F., M. Leitch, and M. Abbasi. 2005. Effects of seeding densities and row spacing on yield and yield components of linseed (*Linum usitatissimum* L.). Acta Agronomica Hungarica 53:309-317.

Klages, K.H. 1932. Spacing in relation to the development of the flax plant. J Am Soc Agron. 24:1-17.

Klebesadel, L., and D. Smith. 1959. Light and soil moisture beneath several companion crops as related to the establishment of alfalfa and red clover. Botanical Gazette 121:39-46.

Krall, J.L., T.J. Army, A.H. Post, and A.E. Seamans. 1965. A summary of dryland rotations and tillage experiments at Havre, Huntley and Moccasin, Montana. 599. Montana Agr Expt Sta Bull.

Puhr, L.F. 1962. Twenty years of soil management on a Vienna silt loam. 508. South Dakota Agr Expt Sta Bull.

Sarvis, J.T., and J.C. Thysell. 1936. Crop rotation and tillage experiments at the Northern Great Plains Field Station 536. North Dakota USDA Tech Bull., Manden, ND.

Shahidullah, M., U. Islam, M. Karim, and R. Mondol. 1997. Performance of four linseed varieties: at different dates of sowing. J Scientific and Industrial Res. 32:186-190.

Vick, B.A., C.C. Jan, and J.F. Miller. 2004. Second-year study on the inheritance of the reduced saturated fatty acid trait in sunflower seed. Proceedings 26th Sunflower Research Workshop, Fargo, ND.

Table 1. Description of each farm which held flax and underseeding on-farm trials in 2005 and 2006 in Iowa.

Location	Planting date	Previous crop	Cultivar	Seedbed preparation	Planting rate (lb A^{-1})	Predominant weeds
NW	9 April 2005 10 April 2006	2004-Triticale 2005-Corn	2005-Bethune 2006-Blend	Disked, field cultivated, harrowed	2005-49 2006-70	lambsquarter
SW	8 April 2005	Soybeans	Norlin	Disked	51	giant and common ragweed; smartweed; morning glories
NC	10 April 2005 13 April 2006	Soybeans	York	Field cultivate 24 hours prior to planting	2005-47.37 2006-52.4	foxtail; smartweed
SE	10-16 April 2005	Soybeans	Webster	Field cultivated and harrowed	50	ragweed; lambsquarter
EC	13 April 2006	Corn	Blend	Disked; field cultivate day before planting	80	grasses
SC	14 April 2006	Alfalfa	Blend	Disked twice and dragged	X	alfalfa
WC	14 April 2006	Fall rye	Blend	Disked; field conditioned	X	mustard

x Missing information

Table 2. Mean monthly air temperature and rainfall near Calumet, IA (NW) in 2005 and 2006. Mean is the average of data from 1951-2007.

	Air Temperature			Rainfall		
Month	2005	2006	Mean	2005	2006	Mean
	--------------------^{o}F †-----------------			-------------------- in. ‡---------------		
March	34	34	33	0.54	4.32	1.74
April	52	52	48	3.24	3.42	2.67
May	57	61	59	3.41	1.19	3.86
June	71	70	69	9.89	4.21	4.59
July	75	77	73	2.44	0.87	3.67
August	71	72	71	2.71	5.97	3.83
September	67	58	62	4.61	4.06	3.18
October	51	47	50	1.67	0.23	1.79

† Tc = (5/9)x(Tf-32)
‡ cm=in. x 2.54
Information source: NWS CO OP

Table 3. Mean monthly air temperature and rainfall near Harlan, IA (SW) in 2005 and 2006. Mean is the average of data from 1951-2007.

Month	Air Temperature			Rainfall		
	2005	2006	Mean	2005	2006	Mean
	----------------------^{o}F †----------------			------------------- in. ‡----------------		
March	37	37	36	1.82	2.74	2.17
April	53	54	50	3.94	4.56	3.29
May	60	62	61	3.43	2.39	4.44
June	72	72	71	4.83	0.46	4.28
July	75	75	75	2.13	6.44	3.82
August	72	72	72	1.09	6.65	3.94
September	68	60	64	1.54	5.05	3.91
October	53	48	52	0.55	1.28	2.22

† Tc = (5/9)x(Tf-32)
‡ cm=in. x 2.54
Information source: NWS CO OP

Table 4. Mean monthly air temperature and rainfall near Hampton, IA (NC) in 2005 and 2006. Mean is the average of data from 1951-2007.

	Air Temperature			Rainfall		
Month	2005	2006	Mean	2005	2006	Mean
	----------------------^{o}F †----------------			----------------- in. ‡----------------		
March	34	34	32	0.76	2.62	2.01
April	52	52	47	4.26	6.2	3.16
May	56	60	59	4.53	1.97	4.34
June	72	69	69	10.08	2.25	4.93
July	74	75	73	4.4	4.7	4.9
August	70	71	70	4.56	3.12	3.97
September	66	59	62	5.34	6.79	3.22
October	52	46	50	0.2	1.6	2.22

† Tc = (5/9)x(Tf-32)
‡ cm=in. x 2.54
Information source: NWS CO OP

Table 5. Mean monthly air temperature and rainfall near Mount Pleasant, IA (SE) in 2005 and 2006. Mean is the average of data from 1951-2007.

	Air Temperature			Rainfall		
Month	2005	2006	Mean	2005	2006	Mean
	----------------------^{o}F †---------------			----------------- in. ‡----------------		
March	40	42	38	1.10	6.30	2.52
April	56	58	52	3.10	3.85	3.42
May	62	64	62	2.55	2.07	4.1
June	74	72	71	3.60	2.95	4.16
July	78	78	75	2.92	3.25	4.43
August	76	76	73	3.25	4.85	4.05
September	72	65	66	3.75	1.15	3.96
October	65	52	54	2.17	2.41	2.84

† Tc = (5/9)x(Tf-32)
‡ cm=in. x 2.54
Information source: NWS CO OP

Table 6. Mean monthly air temperature and rainfall near Toledo, IA (EC) in 2005 and 2006. Mean is the average of data from 1951-2007.

	Air Temperature			Rainfall		
Month	2005	2006	Mean	2005	2006	Mean
	----------------------^{o}F †---------------			----------------- in. ‡----------------		
March	34	35	34	1.00	2.62	2.24
April	53	52	48	2.13	4.17	3.4
May	56	59	60	4.73	2.48	4.51
June	72	68	69	5.31	2.31	4.68
July	74	75	73	2.29	2.31	4.28
August	70	72	71	2.22	6.11	4.32
September	67	60	63	2.45	2.55	3.29
October	52	47	51	0.54	1.89	2.36

† Tc = (5/9)x(Tf-32)
‡ cm=in. x 2.54
Information source: NWS CO OP

Table 7. Mean monthly air temperature and rainfall near Indianola, IA (SC) in 2005 and 2006. Mean is the average of data from 1951-2007.

	Air Temperature			Rainfall		
Month	2005	2006	Mean	2005	2006	Mean
	--------------------^{o}F †------------------			-------------------- in. ‡----------------		
March	38	38	37	0.77	3.27	2.12
April	54	54	51	5.04	4.78	3.58
May	58	62	62	5.13	2.26	4.58
June	72	71	71	4.47	1.70	4.51
July	76	77	75	3.41	4.67	3.90
August	74	74	73	1.63	5.99	3.71
September	70	62	65	0.90	5.81	3.37
October	54	49	53	0.98	1.73	2.40

† Tc = (5/9)x(Tf-32)

‡ cm=in. x 2.54

Information source: NWS CO OP

Table 8. Mean monthly air temperature and rainfall near Carroll, IA (WC) in 2005 and 2006. Mean is the average of data from 1951-2007.

Month	Air Temperature 2005	Air Temperature 2006	Air Temperature Mean	Rainfall 2005	Rainfall 2006	Rainfall Mean
	---------------------^{o}F †----------------			------------------ in. ‡---------------		
March	36	36	34	1.52	3.24	2.19
April	52	53	49	3.47	3.46	3.22
May	58	62	60	2.92	2.22	4.26
June	72	72	70	4.76	0.81	4.73
July	76	76	74	3.56	5.06	3.99
August	71	72	72	2.33	6.56	3.76
September	68	60	63	2.06	5.72	3.11
October	52	48	51	0.22	1.79	2.16

† Tc = (5/9)x(Tf-32)
‡ cm=in. x 2.54
Information source: NWS CO OP

Table 9. Flax grain yield at 8% moisture harvested from all treatments in nine site-years.

Treatment	Grain Yield
	----------lb A^{-1} † ---------
Alfalfa	1459.14 b
Control	1579.13 a
Red Clover	1424.90 b
p-value	0.0066

† kg ha^{-1}=lb A^{-1}x1.12

Means followed by the same letter were not significantly (p=0.05) different.

Table 10. Total biomass yield harvested from all treatments in nine site-years.

Site-year	Total Biomass
	--------- lb A^{-1} †------
SE 2005	775.35
NW 2005	2115.67
NC 2005	3269.10
SW 2005	1510.23
NW 2006	5329.86
NC 2006	2949.04
WC 2006	5579.59
EC 2006	2178.80
SC 2006	2054.87
p-value	0.0001

† kg ha^{-1}=lb A^{-1}x1.12

Table 11. Underseeding and weed biomass yield harvested from all treatments in nine site-years 60 days following flax harvest.

Treatment	Underseeding	Weed
	----------------- lb A^{-1} †-------------	
Alfalfa	1055.4 b	922.9 b
Control	286.5 c	1869.3 a
Red Clover	1705.3 a	752.3 b
p-value	0.0001	0.0001

† kg ha^{-1}=lb A^{-1}x1.12

Means followed by the same letter were not significantly (p=0.05) different.

Table 12. Total oil content of flaxseed at 8% moisture measured in all treatments in nine site-years.

Treatment	Oil Content
	------% ----
Alfalfa	40.7
Control	41.2
Red Clover	41.1
p-value	0.1868

Table 13. Fatty acid profile of flaxseed oil at 8% moisture measured from all treatments in nine site-years.

Treatment	ALA (18:3)	Linoleic (18:2)	Oleic (18:1)	Stearic (18:0)	Palmitic (16:0)
	--------------------------------------% --------------------------------------				
Alfalfa	50.8	13.8 a	24.0	3.9	6.0 a
Control	50.8	13.8 a	24.2	3.9	5.5 b
Red Clover	50.8	13.7 b	24.4	3.9	5.5 b
p-value	0.9379	0.0201	0.3764	0.0839	0.0001

CHAPTER VIII

Straw quality characteristics

Introduction

Currently, office suppliers of the U.S. government have been mandated to provide bio-based products. An Iowa company, which is a large manufacturer of office and home furniture and also a large supplier of government office furniture, has become interested in the use of natural fibers in its manufacturing. Since 1990, this company has been setting the industry standard for reducing waste through recycling and use of bio-based products. They have recently shown interest in the use of flax, kenaf and switchgrass fibers as a means to produce a more environmentally-friendly product. However, currently little information about the characteristics of oilseed flax fiber strength and extraction of chemicals and alcohols for plastics is available. Many producers currently burn flax straw, but with increased pressure to decrease greenhouses gases and the potential marketability of the straw, flax could add diversified incomes for producers. In addition to the fiber, farmers have contracts to sell organic flax seed oil to an established U.S. company in the upper Midwest which began in 2005. Flax seed oil was processed in a new, independently owned crushing facility in Cherokee, Iowa, thereby creating a possible dual market option for flax. Farmers and manufacturers do not currently have adequate information about the potential use of this fiber crop.

Materials and methods

Mechanical testing of isolated bast technical fibers was conducted to determine tensile strength and modulus of flax straw. Straw from cultivars Bethune from PD 1 (11 April 05), PD 2 (21 April 05) and PD 3 (5 May 05) and York from PD 1 (11 April 05) at Central IA was used for testing. Additional samples were analyzed from four farmers' fields. From each sample 25 – 30 stems, uniform in length without defects from being bent or rotten were selected. All usable stems were trimmed at both ends leaving approximately 30 cm (11.8 in.) of middle stem. Stems were placed in a 2000 ml cylinder and distilled water was added until it covered the stems. After two days of soaking, bast strips from the wet flax stems were removed. Bast strips were air dried at room temperature until a constant weight was reached. Strips were trimmed to 25 cm (9.8 in.) lengths. Each flax strip was weighed to the nearest 0.0001 gram before tensile testing. If any defected stems were accidentally used, this resulted in a high coefficient of variation.

Maximum tenacity (Mt), strength, and modulus, stiffness, were both calculated in N tex^{-1}. Maximum tenacity is the breaking load of the straw fiber while tensile modulus is determined from the initial slope of the stress versus the strain curve. Tex is defined as a gram weight of fiber per 1000 meters of fiber length. Tex is used in S.I measurement (International System of Units). Linear density is reported in tex. Linear density is defined as weight of fiber per unit length. Load was measured in Newtons (N).

Testing was conducted according to ASTM D2256-97, Standard Test Method for Tensile Properties of Yarns. Span between grips was 25 mm (6.35 in.). The load rate was 25 mm minute^{-1}. The Com Ten Industries’ L CF0093 Locking Cam Filament grips were used.

Fiber analysis of the straw was completed to determine neutral detergent fiber (NDF) and acid detergent fiber (ADF) (Vogel, 1999). Relative feed value was estimated using the following formulas: RFV= (%DDM x %DMI)/1.29; %DDM= 88.9-(ADF% x 0.779); %DMI=120/%NDF (Holland and Kezar, 1995). Although this formula is not ideal for assessing RFV of flax straw, it is what is currently available to make initial comparisons with other plants. Relative feed value was calculated using the ADF% to estimate the percent digestible dry matter (DDM) and the NDF% to estimate the dry matter intake as a percent of body weight (DMI). Total carbon and total nitrogen were analyzed using the Leco Corporation (St. Joseph, MI) model TrueSpec CN. The crude protein value of the straw was determined: N x 6.25.

Results and discussion

In Central IA PD 3 (5 May 05) had the least NDF and ADF values followed by PD 1 in Central IA (11 April 05) and at Crookston, MN (12 May 05) and finally PD 2 at Central IA (21 April 05) and at Lamberton, MN (23 May 06) had the highest NDF and ADF values (Table 1). Lower NDF and ADF values indicate greater digestibility of the straw in a ruminant animal. If flax straw from PD 3 at Central IA (5 May 06) was fed to a ruminant animal it would be the most digestible of all the treatments. To compare these NDF and ADF values with other forages, a relative field value (RFV) was calculated (Table 2). The RFV for flax straw ranged from 41.3 to 55.3. The RFV of mature alfalfa is 100 while wheat straw is 51. The low RFV of flax indicates that it may be a poor feedstock for ruminants. Protein levels of flax straw ranged from 2.6% to 5.1% comparable to straw which is occasionally used in animal production (Table 4). The protein level of mature alfalfa is 15% while flax straw ranged from 2.6% to 5.1%. The protein of wheat straw was comparable at 4%.

The C:N ratio for flax samples ranged from 56.6 to 110.1. PD 1 (5 May 06), PD 2 (23 May 06) and Crookston, MN samples had similar C:N ratios averaging 106.8 compared to PD 3 Lamberton, MN (5 June 06) which averaged 58.8 (Table 3). This wide range in C:N ratios is comparable to wheat straw which can vary from 100 – 150 (Richard, 1996).

Maximum tenacity and modulus of the flax straw did not follow any obvious trends among planting date treatments or locations in Iowa (Table 5 and 6). After comparing the standard errors of each mean of maximum tenacity, Bethune in PD 3 at Central IA was the least; York in PD 1 at Central IA, Norlin in PD 1 and PD 3 at SW, Webster in PD 1 and PD 3 at SE and Bethune in PD 1 and PD 2 at Central IA responded similarly; York in PD 2 and 3 at NC were the same and finally Bethune in PD 1, 2 and 3 in NW, all treatments in NW IA and Norlin in PD 2 at SW were similar. From this data, no obvious trends exist. Modulus responded similarly among all treatments.

Conclusions

Flax straw is comparably strong (measured as tenacity) to other fibers but has little feed value. The tenacity of unretted oilseed flax (0.384 N tex^{-1}) was similar to the tenacity of less retted hemp (0.389 N tex^{-1}). Unretted linen flax varieties had higher tenacity values at 0.443 N tex^{-1} (Stokke, personal comm., 2006). From this study, individual field treatments did not affect the measured parameters of maximum tenacity or modulus. Feed value of flax straw is similar to wheat straw. Farmers have tried to feed flax straw, which is high in lignin, to cattle and pigs to dispose of the product. Its high C:N ratio suggests that farmers should bale the straw and remove it from the field. High carbon straw left in a field will consume large quantities of nitrogen during the decomposition process and immobilize nutrients, reducing availability to following year's crop. To avoid immobilization of N some farmers have fed flax straw to animals to further break it down before reapplying it as manure to their fields. This could be a potential way of using this high lignin, strong fiber in a farming system.

Literature cited

Richard, Tom. 1996. On-farm composting handbook. Appendix A Characteristics of raw materials TA A.1. NRAES-54. Accessed online on 11/07/2007 at http://compost.css.cornell.edu/OnFarmHandbook/apa.taba1.html.

Holland, Clive and Wes Kezar. (1995). Pioneer Forage Manual A Nutritional Guide. Pioneer Hi-Bred International, Inc.

Vogel, K.P., J.F. Pedersen, S.D. Masterson, and J.J. Toy. 1999. Evaluation of a filter bag system for NDF, ADF, and IVDMD forage analysis. Crop Sci. 39:276-279.

Table 1. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) of flax straw harvested from three plantings in Iowa and two locations in Minnesota in 2005.

Location	Cultivar	PD	NDF	Stdev	SE	ADF	Stdev	SE
			%			%		
Central IA	Bethune	1	77.9	0.7	0.5	63.0	1.1	0.8
Central IA	Bethune	2	82.4	0.9	0.6	67.1	0.8	0.6
Central IA	Bethune	3	72.7	1.4	1.0	58.6	1.0	0.7
Crookston, MN	Bethune	1	77.9	1.0	0.7	63.5	0.8	0.6
Lamberton, MN	Bethune	1	82.8	0.4	0.3	66.7	1.0	0.7

Table 2. Relative feed value (RFV) of flax straw harvested from Central IA and two locations in Minnesota in 2005.

Location	Cultivar	PD	RVF
Central IA	Bethune	1	47.5
Central IA	Bethune	2	41.3
Central IA	Bethune	3	55.3
Crookston, MN	Bethune	1	47.1
Lamberton, MN	Bethune	1	41.5

Table 3. Total carbon to nitrogen ration and organic matter of flax straw harvested from three plantings in Central Iowa and two locations in Minnesota in 2005.

Location	Cultivar	PD	C:N	Stdev	SE	OM	Stdev	SE
						%		
Central IA	Bethune	1	110.1	9.5	6.8	63.9	0.3	0.2
Central IA	Bethune	2	109.2	16.1	11.4	64.6	0.2	0.1
Central IA	Bethune	3	61.0	3.3	2.3	63.9	0.2	0.1
Crookston, MN	Bethune	1	101.2	10.7	7.6	63.9	0.3	0.2
Lamberton, MN	Bethune	1	56.6	3.1	2.2	64.2	0.1	0.1

Table 4. Protein content of flax straw harvested from three plantings in Central Iowa and two locations in Minnesota in 2005.

Location	Cultivar	PD	Protein	Stdev	SE
			%		
Central IA	Bethune	1	2.6	0.2	0.2
Central IA	Bethune	2	2.7	0.4	0.3
Central IA	Bethune	3	4.7	0.3	0.2
Crookston, MN	Bethune	1	2.8	0.3	0.2
Lamberton, MN	Bethune	1	5.1	0.3	0.2

Table 5. Maximum tenacity of flax straw harvested from six sites in Iowa in 2005.

			Maximum Tenacity			
Location	Cultivar	PD	N tex^{-1}	Stdev	SE	N
Central IA	York	1	0.211512	0.040253	0.004918	67
Central IA	Bethune	1	0.224124	0.054521	0.006517	70
Central IA	Bethune	2	0.229007	0.055767	0.006158	82
Central IA	Bethune	3	0.185127	0.047405	0.00612	60
SE IA	Webster	1	0.225472	0.057649	0.010191	32
SE IA	Webster	3	0.219233	0.060252	0.011	30
SW IA	Norlin	1	0.245086	0.064439	0.011966	29
SW IA	Norlin	2	0.28195	0.068238	0.013929	24
SW IA	Norlin	3	0.21779	0.061704	0.011265	30
NC IA	York	2	0.246653	0.055781	0.009566	34
NC IA	York	3	0.246258	0.066257	0.011043	36
NW IA	Bethune	1	0.283907	0.078241	0.020202	15
NW IA	Bethune	2	0.32642	0.073056	0.013338	30
NW IA	Bethune	3	0.285514	0.066783	0.012621	28
NW IA	Bethune	1	0.316375	0.064615	0.014448	20
NW IA	Bethune	2	0.30003	0.067438	0.01508	20
NW IA	Hanley	2	0.281679	0.067811	0.018123	14
NW IA	York	2	0.292561	0.05979	0.014093	18

Table 6. Moldulus of flax straw harvested from six sites in Iowa in 2005.

Location	Cultivar	PD	Modulus N tex^{-1}	Stdev	SE	N
Central IA	York	1	2.376612	0.55172	0.067403	67
Central IA	Bethune	1	2.294614	0.758667	0.090678	70
Central IA	Bethune	2	2.772755	0.556692	0.061476	82
Central IA	Bethune	3	2.41045	0.662981	0.08559	60
SE IA	Webster	1	2.275197	0.552569	0.097681	32
SE IA	Webster	3	2.4588	0.618762	0.11297	30
SW IA	Norlin	1	2.48431	0.565411	0.104994	29
SW IA	Norlin	2	2.843167	0.624552	0.127486	24
SW IA	Norlin	3	2.4644	0.59804	0.109187	30
NC IA	York	2	2.378	0.497841	0.085379	34
NC IA	York	3	2.348167	0.51663	0.086105	36
NW IA	Bethune	1	2.655333	0.440133	0.113642	15
NW IA	Bethune	2	2.887667	0.496928	0.090726	30
NW IA	Bethune	3	2.649964	0.548686	0.103692	28
NW IA	Bethune	1	2.9038	0.386407	0.086403	20
NW IA	Bethune	2	2.9981	0.562844	0.125856	20
NW IA	Hanley	2	2.963214	0.528755	0.141316	14
NW IA	York	2	2.918278	0.542496	0.127868	18

CHAPTER IX

Summary

In 2005 and 2006, research was conducted in Iowa on a crop, flax, that previous to 1949 had been grown throughout the upper Midwest but recently had been planted on less than 1000 A in the state. Based on the research results from this project several suggestions can be made for farmers and future researchers to successfully produce this crop in Iowa. An early planting date is critical to avoid warm summer temperatures during grain fill. Flax plant growth during cooler temperatures not only produces greater grain yields but also increases the concentration of unsaturated oil, two critical qualities of flax grain for both farmers and industry.

Of the five cultivars evaluated, farmers will want to plant York because it produced the highest grain yield. However, the current industry buyer in Iowa buys Bethune and Norlin, because these cultivars yield the highest oil content. A more inclusive cultivar trial will need to be conducted to assess which cultivars are best suited for Iowa’s climate.

From the four studies conducted which assessed weed management strategies to control weeds during flax growth and development, none proved to be consistently effective. However, planting an underseeding proved crucial to controlling weeds following flax harvest. No obvious correlation between the weed biomass values and grain, oil and ALA yield existed. Even an herbicide application, the historically used method of weed control, proved difficult to predict.

One finding that is missing from the current literature on flax is field treatments’ effect on the fatty acid profile. Little known information was found in a review of the literature and from an inquiry to flax breeders and physiologists in Canada. This could be an area of future investigation.

Flax straw could have potential market value as a substitute for other natural fibers in the furniture and similar industries. However its value as a feedstock for animal production is very low. Further uses for this biomass could develop with increased need for lignocellulosic material for ethanol production. However, because of the low yield compared to other feedstocks, it may not be a profitable co-product.

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