Weed management in reduced-input no-till flax production

by

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Abstract

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The goal of the project was to enhance the period of weed growth prior to seeding in order to reduce weed emergence and weed competition after the crop has been planted. Weed growth was stimulated using either light tillage or by applying nitrogen fertilizer early in the spring. Light disturbance significantly increased pre-seed weed emergence while early applied nitrogen did not appear to have an effect. Post seeding weed emergence levels and weed biomass were similar among the light tillage and early nitrogen treatments. Therefore the goal of decreasing weed competition after seeding was not attained. Future research should focus on long-term strategies to reduce weed populations in field rather than seasonal strategies.

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Table of Contents

List of Tables

List of Figures

1.0 Introduction

Flax does not compete well with weeds and therefore needs extensive management for effective weed control. In the past, farmers used crop rotation, tillage, and seed cleaning to limit weed competition (Lockhart et al. 1990). In the last half-century, herbicides have become the control tool of choice for farmers because of their high efficacy (Dent 2005).

Although pesticides are relatively easy to use and provide good weed control, there is demand for flax produced with little or no pesticides (Magnusson 2002). Health conscious consumers often perceive pesticides negatively and will pay a premium to have flax produced without any pesticides (Magnusson 2002).

Coupled with consumer demand for pesticide reduction (Major 1992) are calls from the academic world to reduce dependence on pesticides. Integrated Pest Management (IPM) programs have been developed to help farmers find alternatives to pesticides and to use pesticides more effectively. IPM programs suffer from lack of participation among farmers partly because there is usually little or no framework for the farmer to follow and immediate economic benefits may be limited (Nazarko et al. 2005). In response to this, pesticide reduction schemes have been developed that aim to give farmers a framework to use IPM practices while also commanding a price premium (Williamson and Buffin 2005).

The focus of this research was to identify methods to produce flax under a reduced pesticide scheme. Pesticide Free Production was chosen as the framework for this study. Pesticide Free Production (PFP) was developed in Manitoba by researchers, extension workers, and farmers. Flax was chosen as the crop for this study because previous research has shown that it is the most difficult crop for farmers to grow using this system (Nazarko et al. 2003).

No-till and minimum tillage is gaining popularity in the Northern Great Plains (Bullied et al. 2003) and was chosen as the tillage system for this research. The weed seedbank in no-till systems is easily influenced through light tillage because of its close proximity to the soil surface (Mulugeta and Stoltenberg 1997, Yenish et al. 1992). It was hypothesized that early stimulation of this seedbank would deplete enough of the seedbank prior to seeding so as to allow less weed competition after the crop was planted. It was further hypothesized that late seeding would be superior to early seeding using these weed stimulation methods due to more time available for weeds to recruit. The specific goals of the project were:

1) To determine whether weed growth could be stimulated early in the spring by light disturbance to the soil surface.
2) To determine whether weed growth could be stimulated early in the spring by early nitrogen fertilizer application.
3) To determine whether weed stimulation strategies would affect post-seeding weed numbers and weed pressure (biomass).
4) To determine the effect of flax seeding date on weed stimulation strategies.
5) To determine whether weed stimulation strategies would affect flax yield and quality.

2.0 Literature Review

2.1 Agriculture in the Western Canadian Prairies

2.1.1 Geography

The Western Canadian Prairies are bound to the west by the Rocky Mountain Range and to the north-east and east by the Canadian Shield. To the north lies the tundra land of the Arctic and to the south lies the continuation of the Northern Great Plains into the United States of America.

Settlement of the Western Canadian Prairies was very quick. The fertile land was covered only by natural grassland vegetation, and so usually only needed to be ploughed to be prepared for agricultural use (Horner 1980). Up to the turn of the 20^{th} century less than 9 million acres had been improved for farmland. Between then and the First World War (1914) approximately 30 million acres were improved and then again between the First and Second World War's (1939) a further 30 million acres were improved (Horner 1980). After these two periods of rapid expansion new farmland came less from improving new tracts of land and more from opening land within existing farm boundaries.

According to the Canada Land Inventory of 1965 over two thirds of Canada's potential arable farmland (classes 1 to 4) is found in the Prairies. Of the cultivated portion of this land, over half is found in Saskatchewan and nearly one third in Alberta with the remaining portion of it in Manitoba (Horner 1980). The three major soil zones of the Prairies with agricultural significances are the brown, dark brown, and black soils.

Brown soils are found mainly in the south-eastern parts of Alberta and south-western parts of Saskatchewan. These soils tend to be shallow, loamy and low in organic matter. This soil zone is typified by moisture deficits and serious wind erosion problems (Campbell 1990). Radiating out from this zone to cover most of the southern parts of Alberta and Saskatchewan is the dark brown soil zone. It is slightly less shallow, loamy, and higher in organic matter. There are fewer problems with wind erosion in these soils, and this zone experiences fewer problems with moisture deficits (Campbell 1990). Black soils border this region in Alberta and Saskatchewan and spill over to cover most of southern Manitoba. These soils are typified by a deep A horizon, the highest organic matter content of the Prairie soils, and the least problems with moisture deficit and erosion (Campbell 1990). Within this zone lies the Red River Valley which is one of the few areas in the zone that usually does not suffer from moisture deficit and has deep fertile soils (Horner 1980).

2.1.2 Agriculture & Settlement

After settlement, the new focus was on keeping the Prairies thriving. Attention turned to issues such as transportation, marketing organizations, income stabilization, and crop insurance (Horner 1980) as farmers moved towards large, highly mechanized operations (Campbell et al. 1990). Two people can now easily run an 800 ha farm; an increase in efficiency of five-fold in 80 years (Horner 1980). Most farmers have specialized into only one or two main crops or livestock. This simplifies production because equipment and knowledge can be focused on a few enterprises, but makes income very risky due to dependence on weather and markets (Campbell et al. 1990).

Soil quality has declined since the land was first broken (Campbell et al. 1990). It is an inevitable condition of agriculture than when the natural system is upset nutrients, organic matter, and moisture will be depleted. Campbell et al. (1990, p9) concede that "good soil quality is not always compatible with the realities of short-term economic circumstances". They further state that with crop rotations and good management, soil quality can be sustained and possibly improved.

2.1.3 Reduced Tillage

Tillage has been essential to weed control and seedbed preparation for as long as agriculture has existed (Lockhart et al. 1990). Unfortunately, tillage has many drawbacks such as greater soil moisture loss, greater organic matter degradation, and increased wind and water erosion risk (Lafond et al. 1996). Farmers have reduced tillage dramatically over the past twenty years (Lafond et al. 1996). The reduction in the price of glyphosate herbicide, along with learning how to adapt herbicides to reduced tillage systems removed the weed control barrier to tillage reduction. The development of machinery capable of accurately placing seed into un-tilled ground removed the seedbed barrier to reduced tillage (MANDAK 1991).

The concept of reducing tillage to leave more residues on the soil surface stretches as far back the end of the 19th century (Lafond et al. 1996). The first direct seeding experiments were conducted at Brandon, MB and Indian Head, SK between 1892 and 1896 (Janzen 2001). However, it was not until the past 30 to 40 years that machinery availability (Lafond et al. 1996), herbicide development (Pretty and Hine 2005) economic necessity (Lafond and Derksen 1996), and farmer initiative (MANDAK 1991) has made reduced tillage possible. Reduced tillage is one way to bring agricultural systems more in line with natural systems. A natural system rarely has the soil disturbed to the extent that tillage disturbs it. Agriculture can never be as ecologically sound as a natural system, but the more it mimics a natural system the more sustainable it will be (UMPSD 2005).

2.1.4 Flax

Flax has been cultivated for thousands of years for its health benefits (Flax Council of Canada 1998b). Only recently has science been able to explain and quantify those benefits. Flax has high amounts of alpha-linolenic acid (ALA), lignans, and fibre. ALA is an omega-3 fatty acid which has been found to be lacking in most North American diets. It has been linked to healthy infant growth, prevention of heart disease, thrombosis, hypertension and inflammatory and autoimmune disorders (Flax Council of Canada 1998a). Lignans (not to be confused with *lignins*) are 75-800 times higher in flax than in any other plant-based food and may help protect against certain cancers (Flax Council of Canada 1998c). Flax has high amounts of water insoluble fibre (which is low in most North American diets) and is beneficial for regular bowel movements, appetite suppression (because of bulk), buffering blood glucose levels, and lowering blood cholesterol levels (Flax Council of Canada 1998b).

Flax is a relatively small crop in the world markets (FAOSTAT data 2005). Even in Canada where approximately one-third of the world's supply (Figure 1) is produced it is a relatively small crop (FAOSTAT data 2005). The western provinces produce nearly all of Canada's flax with Saskatchewan leading and Manitoba producing most of the remainder (Figure 2). The majority of Canadian flax is exported. Manitoba exports to 37 countries with the biggest buyers being Belgium, the U.S.A., and the Netherlands (MAFRI 2001).

In Canada, insect pests do not normally cause harm to the flax crop. Only one insect is known to attack flax specifically (flax bollworm, *Heliothis ononis*). Other agricultural pests can cause problems if the conditions are right (Flax Council of Canada

2005a). Breeding and fungicidal seed treatments have reduced the threat of disease on flax in Canada. Proper rotation (3 years or greater) along with practices that allow the canopy to dry out easily also contribute to disease prevention (Flax Council of Canada 2005a).

The "Achilles Heel" of flax is its lack of competitiveness towards weeds (O'Donovan and Sharma 1983). Flax does not rapidly cover the soil surface allowing weeds to recruit later in the growing season and out-compete it for nutrients and space. Weed competition not only reduces yield but also leads to higher dockage in the grain due to high amounts of weed seed. Post-seed mechanical weed control is not recommended for flax because the plant is so weak that large amounts of damage occur. Carr et al. (1997) found flax stands reduced by 14 to 44% because of post-seeding tillage. Herbicides are now the main weed control tool for flax.

2.2 Pest Control in Agriculture

2.2.1 Pesticide Use in Agriculture

The basis for, and the beginning of, the movement to reduce agricultural inputs was primarily the result of the proliferation of the use of pesticides in agriculture. Up to the beginning of the 20th century, pesticides were not in widespread use. However, many people had discovered the pesticidal properties of common compounds (e.g. inorganic mercury and arsenic used to kill body lice in China) and natural plant derived compounds (e.g. pyrethrum from chrysanthemum flowers) (Pretty and Hine 2005).

If any one chemical could mark the beginning of this new era in agricultural pest control it would be dichlorodiphenyltrichloroethane (DDT), which was discovered in 1939 and manufactured beginning in 1943 (Pretty and Hine 2005). While initially seen

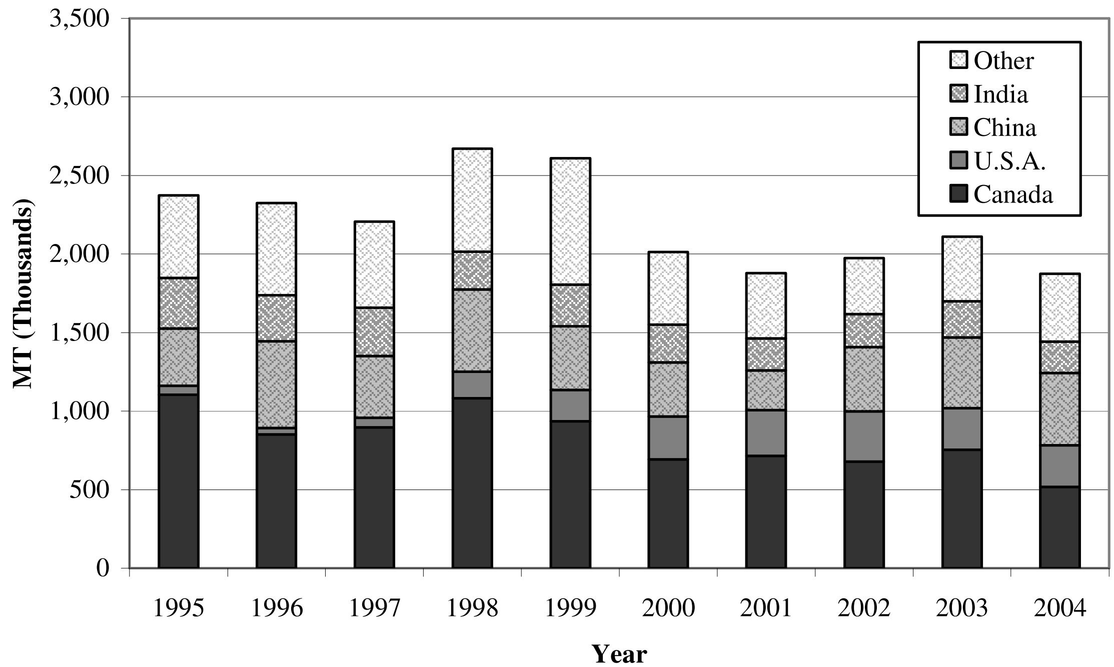

Figure 1. World flax production (1996-2004).
Source: FAOSTAT data (2005).

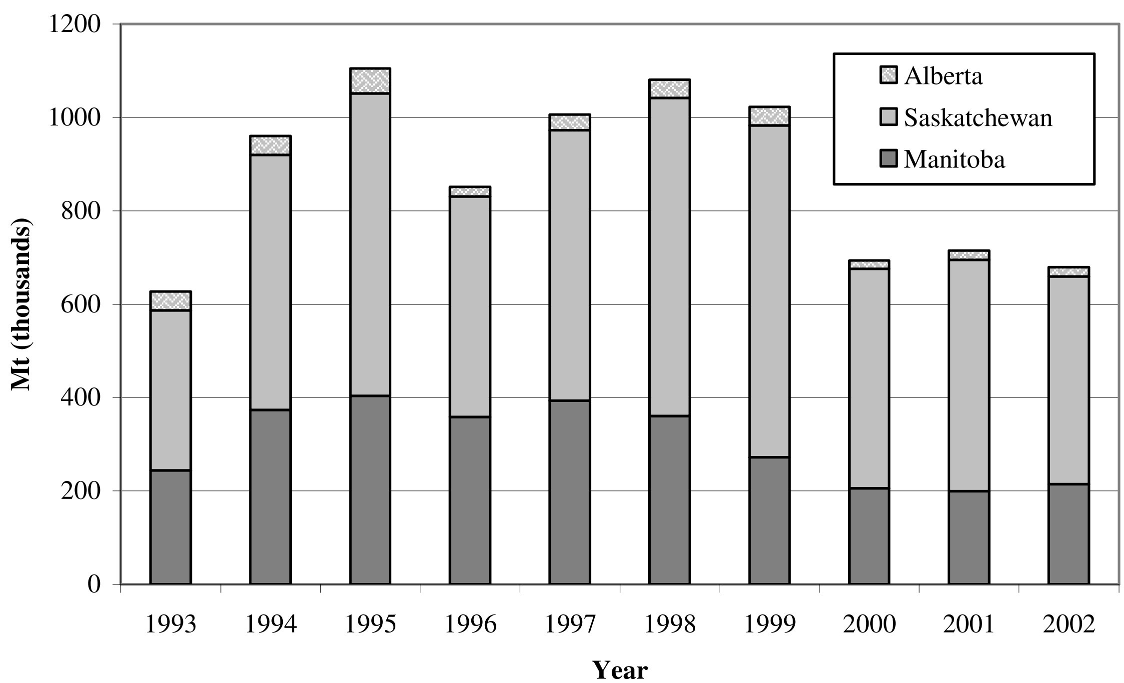

Figure 2. Canadian flax production by province (1993-2002).
Source: Statistics Canada (2003).

as a great benefit for de-lousing people (Pretty and Hine 2005) it soon became apparent that there were many un-intended negative effects of DDT and there were calls in the popular press to re-evaluate its use. Between the periods of 1944 to 1961 the ratio of positive to negative press on DDT slowly fell (Gunter and Harris 1998) culminating in the release of Rachel Carson's historic work *Silent Spring* in 1961 on the negative effects of synthetic organic pesticides.

Pesticide use exploded in the 1960's, recording the highest annual growth rate of any decade since (Pretty and Hine 2005). As time went on and technology improved, pesticides were developed with less human toxicity, less environmental persistence, and greater efficacy for only the targeted pests (weeds, diseases, and insects). Pesticides helped advance modern farming by decreasing yield losses, cutting down or eliminating the drudgery of field work, and cutting labour costs on menial physical tasks. Despite this, consumers would like to see agriculture return to the non-chemical means of production from the past because of the negative perception of pesticides (Major 1992). Dent (2005) points out that farmers are perfectly justified in wanting to adopt chemical pest control even in light of the health and environmental risks: "Pesticides were and are effective (visibly so in many cases), are relatively low-cost, easy to use, and versatile"

2.2.2 Organic Agriculture

Organic agriculture developed in tandem to the rise in the use of synthetic pesticides. This type of agriculture is "organic" in nature – many movements with many different beliefs and levels of restriction (Chhonkar 2003). The most common definition of organic agriculture would include the complete absence of synthetic pesticides or fertilizers (Nazarko et al. 2005). Differences between groups would arise in what “natural” fertilizers could be used (or whether they could be used at all), production practises, and how long or to what extent farm certification would take place. Certification is essential for organic producers to command a price premium from consumers. Farmers in Canada wishing to try organic production must typically wait 36 months for certification, during which time they cannot sell their crop or produce as organic at the premium price (Nazarko et al. 2005). Additionally the entire farm is usually expected to be certified in organic production within a certain time period from the initial field certification.

Organic agriculture claims to be more environmentally friendly and claims that it could easily feed the world if everyone began farming using organic methods (Chhonkar 2003). By eliminating pesticides and synthetic fertilizers and trying to build more robust cropping systems that cycle nutrients and resists pest, organic agriculture can be more environmentally friendly (UMPSD 2005). However, it still has drawbacks such as increased reliance on tillage (leading to soil erosion) (UMPSD 2005), nitrate leaching from the soil (because manure breakdown may not be synchronized with crop uptake) and lower crop yields (Chhonkar 2003). Organic production alone cannot feed the world’s population. There are insufficient levels of nutrients available from organic and natural sources and yields are reduced by uncontrolled pests (Chhonkar 2003).

2.2.3 Integrated Pest Management (IPM) and Integrated Weed Management (IWM)

While the organic movement was more grassroots in origin, Integrated Pest Management (IPM) was more academic in origin. Some of the first IPM programs in the United States were developed in the 1960’s and 1970’s in response to pesticide resistance and the subsequent secondary outbreaks of pest problems (Dent 2005). IPM in the

United States tended to develop into a system based on the better use of pesticides (e.g. economic thresholds) whereas IPM stemming from south-east Asia tended to focus on understanding the biology of pest / crop interactions and creating an environment where pesticides were used only when necessary (Dent 2005).

Integrated Weed Management (IWM) stems from IPM. Weeds are different to manage than insects or diseases because they are stationary, competition usually does not result from just one species, and beneficial species usually cannot be used to control or limit weed populations (Nazarko et al. 2005). IWM, like IPM, uses a variety of control measures (cultural, genetic, mechanical, biological, chemical) which when combined can provide a measure of weed management (Swanton and Weise 1991).

Organic agriculture tends to survive because organic producers are committed to the philosophy of pesticide and synthetic fertilizer elimination and sustainability, whereas IWM (and IPM) programs suffer from lower rates of adoption because farmers are not committed to them (Van Acker et al. 2001). While farmers may be committed to safe food and environmental stewardship, they still are confined by economics and tend use the system that gives them the greatest return on their investment.

2.2.4 Reduced-Input Systems

The academic literature tends to support the development and implementation of integrated systems (IPM/IWM) (Williamson and Buffin 2005, Swanton and Weise 2001, Nazarko et al. 2005, Chhonkar 2003). Further, although organic systems can provide environmental and economic benefits, there is scepticism that organic truly is the best method for farmers to use (UMPSD 2005, Williamson and Buffin 2005, Chhonkar 2003, Nazarko et al. 2003). Integrated systems suffer from lack of participation from main-stream farmers due to lack of structure or economic incentive (Williamson and Buffin 2005) and organic systems suffer from lack of participation from main-stream farmers due to high commitments and a paradigm shift in management style (Nazarko et al. 2005).

To reach this goal of introducing farmers to the principles of IPM and IWM there must be a "draw" (Van Acker et al. 2001). Reduced input systems try to bridge this gap between conventional agriculture and IPM/IWM systems. There is no one model for a reduced-input system as they will vary according to the demands of the crop, willingness of farmers, available technology, local or global markets, extension knowledge, and government support (financial or otherwise).

Economic incentives are usually the best way to involve farmers in reduced input systems (e.g. premium market price and/or reduced input cost). In order to command a premium market price there should be system that can guarantee that these practises have been carried out. The challenge will always be in developing the market in tandem with developing and implementing the production system.

2.2.4.1 Pesticide Free Production in Manitoba

In Manitoba, Canada, Pesticide Free Production (PFP) was developed to bridge the gap between farmers who were interested in reducing pesticide use but not wanting to commit to organic production. PFP allows the use of synthetic fertilizers but restricts farmers from using genetically modified organisms and pesticides (or having active residual pesticides in the soil) from the time of crop recruitment to marketing (UMPSD 2005).

Work by Schoofs et al. (2005) demonstrated that the concept of a PFP production system could work and could be managed so as not to affect the long term productivity of the farm. In their work an annual based system (flax-oat-canola-wheat) was compared with a forage based system (flax-oat-alfalfa-alfalfa) where PFP was practiced in either one year in four (oat only) or two years in four (flax and oat). In general, forage based systems perform better under reduced input or organic rotations because the frequent harvest of the forages is able to reduce the weed seedbank by not allowing weeds to produce viable seed (AAFC 2004). However, in the study by Schoofs et al. (2005), the forage system failed to reduce weed pressure, and possibly contributed to the increase in weed pressure, because of the dominance of weeds that are adapted to the frequent mowing in forage systems. Had herbicides been used in the alfalfa these weeds may not have risen to high levels. The most significant conclusion from this trial was that post-PFP crop yields were not affected by one or two years of PFP production. In the annual based rotation, higher initial weed densities were found after PFP production when compared to a non-PFP system, but normal amounts of herbicides were able to effectively control these weeds. In the forage based rotation the alfalfa crop had a higher percentage of weed biomass after PFP crops, but within a year weed biomass was at the same level as a non-PFP system. Although the total forage yield was not affected after PFP crops, the quality was affected, which could be a problem depending on the digestibility of the forage and the needs of the livestock producer. The PFP oat yields were never affected by the lack of herbicides whereas the PFP flax yields were reduced in the weedier forage rotation. This is consistent with Frick (1998) who showed oats to be much more competitive than flax under high weed pressure. Farmer experience also shows greater success growing PFP oats than PFP flax (Nazarko et al. 2003).

Concurrent to the Schoofs et al. (2005) research-based study was a participatory-based study conducted by Nazarko et al. (2004). Farmers were recruited in 1999 and 2000 to volunteer part of their crops for PFP in the following year. At the time there were no premium marketing opportunities and participants were not given any financial compensation for attempting to grow a PFP crop (Nazarko et al. 2004). Some producers continued to use the PFP system beyond 2001 and a co-operative was formed by the farmers to try to develop the market. The co-op eventually failed; which was in part due to lack of approval from the federal food labelling agency (Rance 2004). The top reason for farmers participating in this system was the possibility of input reduction (Nazarko et al. 2004). Additionally, it was found that many more who started but did not complete PFP may have continued if there were premium prices available. Although health concerns over pesticides, pesticide resistance, and environmental concerns ranked high, it was still the economic factors that drove the program (Nazarko et al. 2004).

Magnusson (2002) did an economic analysis of the PFP system through surveys of consumers in Calgary, Winnipeg, and Toronto. His research indicated that Canadian consumers were interested in purchasing PFP foods if they were available. The average consumer would be willing to pay a low to moderate premium, but health conscious and environmentally conscious consumers would be more willing to pay higher premiums (Magnusson 2002). The majority of consumers appear make their decisions based on economics rather than on beliefs on food safety or environmental concerns. It appears that the majority of consumers believe that government regulations on pesticide use allow a high level of food safety.

In summary, work by Schoofs et al (2005) shows that the PFP system can be implemented in one or two years out of four and not affect crop yields in non-PFP years. Knowing the weed populations in the field will help to select non-PFP crops that will best suppress weeds for the PFP crops. PFP systems will be more successful among farmers with a higher price premium (Nazarko et al. 2004) and will be more successful among consumers with little or no increase in cost (Magnusson 2002). Considering that the cost of the raw product compared to the cost of the product to consumers is usually quite low, this may not be an insurmountable issue. Farmers may also be able to capture more of the product dollar by organizing in marketing co-ops such as the one that was formed in Manitoba.

2.3 Weed Recruitment

2.3.1 General

Recruitment is defined as the germination of the seed and establishment of the seedling above the soil surface (Boyd and Van Acker 2003). The three major factors in determining whether a seed will germinate are soil temperature, soil moisture, and the gaseous environment surrounding the seed (Benech-Arnold et al. 2000). Of the three factors, soil temperature and soil moisture are the most important (Boyd 2003) and are the easiest to measure in a field situation. Natural populations of seeds have elaborate systems that limit germination until these factors are present. For example, most strict winter annuals will not germinate in the spring even though moisture and temperature conditions may match their requirements for germination. Dormancy is at its greatest after the cold temperatures of the winter and is only broken when the hot temperatures of the summer are present (Benech-Arnold et al. 2000).

Crops do not generally exhibit dormancy because it is undesirable in crop plants and has been selected against by plant breeders (Benech-Arnold et al. 2000). Individual crop plants will generally emerge at nearly the same time and maintain similar rates of development during the growing period. Weed populations, on the other hand, will emerge depending on dormancy release within the population. This can be related to many factors such as tillage system and crop growth (Benech-Arnold et al. 2000).

2.3.2 The Soil Seedbank

Weeds are part of a natural system and will therefore build a natural population of seeds in the soil. This population is commonly referred to as the soil seedbank because seeds will always be added and removed from the soil both spatially and temporally.

Weed seedbanks are much larger than the density of weeds that will successfully recruit. For example, Mulugeta and Stoltenberg (1997) found that less than 5% of viable giant foxtail (*Setaria viridus)* seeds emerged from a small seedbank of 210 seeds m^{-2} while less than 1% of viable lambsquarters (*Chenopodium album*) seeds emerged from a very large seedbank of 21 365 seeds m^{-2}. It is estimated that generally only 2 to 6% of seeds will ever be successfully recruited in a field situation (Yenish et al. 1992).

With the advent of herbicides it was believed that the soil seedbank could be eradicated (Ghersa et al 2000). However, the adaptability of weeds soon showed that this was not feasible. Eradication has been successful for some species (such as witchweed (*Striga asiatica*) and summer cypress (*Kochia scoparia*)) that posed a high risk for farmers; however, this took considerable will among governments and cost large amounts of money (Swanton and Booth 2004).

Because soil seedbanks are dynamic in space and time, it is very hard to predict the weed seedling population based on weed seedbank numbers (Swanton and Booth 2004). The seedbank will determine the potential for amounts and types of species but the environment and farm practices will modify the numbers and timing of recruitment. Seedbanks are very robust and can recover from near depletion in a very short amount of time. Yenish et al. (1992) cite a study by Burnside et al. (1981) in which they depleted the soil seedbank by 95% but it returned to 50% of its original level in one year solely from weeds going to seed.

The evolutionary goal of any seed is to continue its genes into the next generation. An “r-type” reproductive strategy relies on producing as many seeds as possible with the hopes that at least a few of them will recruit and reproduce. These seeds will germinate over a large range of conditions and are usually referred to as generalist or seed-limited species (Boyd 2003). Dormancy will usually be short in these seeds, as they will germinate as soon as the immediate conditions are met for germination. On the other end of the spectrum is the “k-type” reproductive strategy which relies on giving each seed a greater chance of survival. These species are referred to as specialist or microsite-limited because they will only germinate when the exact conditions are met that will give a very high chance of survival (Boyd 2003). These seeds may lay dormant for years if the conditions are not met and will form a persistent seedbank that is not easily influenced.

2.3.3 The Seed Microsite

In order to be successfully recruited, a seed must be surrounded by an appropriate microsite. A microsite is the physical location in the soil where all of the factors necessary to break dormancy are present along with all of the biological requirements for recruitment (Boyd 2003). The biological requirements for successful recruitment are sufficient soil temperature, sufficient soil moisture, and the proper gaseous environment surrounding the seed (Benech-Arnold et al. 2000).

Soil temperature is the most important biological factor driving recruitment of seedlings (Forcella 1998; Grundy and Mead 2000). Soil temperature is used rather than air temperature because it represents the actual conditions surrounding the seed and tends to give the best predictive value in models (Forcella et al. 2000). Growing Degree Days (GDD) are used when modelling weed recruitment and are calculated by subtracting a threshold temperature (the temperature below which no recruitment or development occurs) from the average temperature of the day. The greater the number of measurements through the day (e.g. once per hour rather than just the high and the low) the more accurate the GDD value will be. For example, a day with an average temperature of 15°C and a threshold temperature of 5°C will have 10 GDD. In this example, the amount of weed growth on one calendar day with 10 GDD would take two calendar days if there were only 5 GDD accumulated per day.

The second most important biological factor for weed recruitment is soil water potential (Forcella 1998; Grundy and Mead 2000). Soil water potential is a measure of the amount of water available to the seed and can be directly related to the available water in the seed (Boyd and Van Acker 2004a). Soil water potential is affected by soil texture. Clay soils hold water more tightly than sandy soils which means that soil water potential will be lower (more negative) in a clay soil than a sandy soil at a given soil water volume. Since soil water potential cannot be easily measured in the field, soil moisture is measured through the period of interest and this is related to soil water potential through separate pressure plate experiments. Unfortunately, creating these relations is a time consuming processes that cannot be easily transferred from location to location (Boyd 2005). Soil moisture is difficult to measure with accuracy and efficiency even with advances in technology such as TDR (Time Domain Reflectometry) (Topp et al. 2003).

The WeedCast computer model uses soil description, initial moisture level, soil temperature and rainfall to estimate soil water potential, but this method is crude at best (Forcella 1998). When modeling weed recruitment soil water potential acts more like an on and off switch: stopping growth when too low (dry) and beginning growth again when it is adequate (moist) (Forcella 2000). Unlike temperature, higher soil moistures (up to field capacity) will have little effect on increasing weed growth.

The final biological requirement for recruitment is a suitable gaseous environment. A seed needs oxygen to respire and suitable gas exchange to rid itself of waste products. This requirement can also act as a signal to the seed that it is not in the correct conditions for growth (e.g. on the surface, too deep, flooded area) which can force it back into dormancy (Boyd and Van Acker 2004b). Benvenuti (2003) showed that inhibition response to soil type and depth is not related to the soil type *per se*, but rather to the gaseous environment surrounding the seed. In clay soils, the hypoxic conditions that occur because of seed germination can inhibit other seeds because of poor gas exchange through the soil. In another experiment, Benvenuti (2003) showed that the lower recruitment in clay soils from deep layers is not the result of suicide germination but from the seeds not germinating because of inhibition by a poor gaseous environment.

Lightly compacting a soil can help to increase recruitment by increasing the number of suitable microsites in the soil. The Canola Council of Canada (2005) recommends packing in the row of seeding to promote more rapid recruitment of the crop seed through better seed / soil contact. Although this may increase weed recruitment in the intra-row area, it may help to decrease recruitment in the inter-row area. Conversely, heavy compaction may decrease recruitment by lowering the quality of the gaseous environment surrounding the seed or making it too hard for the seed shoot and radicle to penetrate through the soil. Boyd and Van Acker (2003c) tested the effect of heavy compaction (wheel traffic) on weed and crop seed recruitment on clay (Winkler series) and fine sandy loam (Hochfeld) soils near Carman, MB. On the clay soil, recruitment was generally un-affected or lowered when the soil was compacted whereas recruitment was un-affected or increased in a fine sandy loam soil. Differences in the response of species were found. In general, wheat recruitment was lowered in both soils due to compaction, whereas most weed species had greater recruitment in the fine sandy loam soil. This highlights the fact that each species will respond differently to soil conditions and will each have their own specific microsite requirements.

2.3.4 Dormancy

Even when all of the biological requirements for recruitment are present it may not be an appropriate time to germinate. Dormancy can be defined as “an internal condition of the seed that impedes its germination under otherwise adequate hydric, thermal, and gaseous conditions" (Benech-Arnold et al 2000).

In areas that have many constraints to growth (e.g. dry seasons, cold winters), dormancy will be more pronounced than areas that have few constraints (e.g. wet tropical areas) (Forcella et al. 2000). If the seed were to base germination on soil moisture and soil temperature alone it could lead to, among other things, germinating too deep in the soil, emerging at the wrong time (too early or late), or emerging when there are already too many seedlings to compete with.

When a seed is dispersed from its mother plant it will usually exhibit primary dormancy, which prevents the seed from germinating immediately when it is likely the end of the growing season (Benech-Arnold et al. 2000). Once primary dormancy is released, the seed may either germinate if the conditions are right or it may be induced into secondary dormancy. A seed may cycle between dormancy and non-dormancy many times in its life.

Benech-Arnold et al (2000) identify two distinct types of dormancy factors: 1) factors which modify the level of dormancy (i.e. cycle the seed between dormancy and non-dormancy) and 2) factors which release the ultimate constraints on dormancy. As a seed moves into a less dormant state it will be easier to remove the ultimate constraints on dormancy; conversely, as a seed moves towards dormancy it will be harder, if not impossible, to remove the ultimate constraints on dormancy. Factors usually interact with each other making it difficult to classify them discretely between the two categories.

Just as temperature is the major biological requirement for germination, it is also the major factor in both modifying the level of dormancy and releasing the ultimate constraints on dormancy. Rising temperatures can lower the dormancy level. Fluctuating temperatures can also lessen seed dormancy (Forcella et al. 2000) or remove the ultimate constraint (Benech-Arnold et al. 2000). Cold winter temperatures will induce dormancy in winter annuals, and hot summer temperatures will break dormancy allowing them to germinate at the next opportunity (i.e. cooler fall temperatures and adequate soil moisture) (Benech-Arnold et al. 2000).

Soil water potential (Benech-Arnold et al. 2000) and the gaseous environment surrounding the seed (Benvenuti 2003) can influence dormancy levels, although separating dormancy effects and biological effects is difficult. Extended periods of adverse conditions may induce dormancy, but a sudden change (e.g. soil moisture increase or levels of toxic gases decrease) may switch dormancy off allowing the seed to grow. Other factors (e.g. light or nitrate concentration) can terminate dormancy, although they are not typically a part of models because of their inconsistent effect or relatively minor role (Forcella et al. 2000).

2.3.5 Effect of Tillage and Crop Rotation on Weed Recruitment

When a soil is left un-disturbed, such as in a natural system, seeds will occupy a specific niche within the soil profile. Seed shape and seed persistence are believed to be important factors determining where a seed will be found within the soil (Ghersa and Martinez-Ghersa 2000). Tillage randomly mixes seeds within the soil profile which upsets this natural balance.

Yenish et al. (1992) studied the effects of mouldboard ploughing plus spring disking (conventional tillage), chisel ploughing plus spring disking (minimum disturbance), and no-tillage on the vertical distribution of weed seeds by sampling the seedbank of a long term study incrementally to 19 cm. Mouldboard ploughing had a near even distribution of seed throughout the entire depth, chisel ploughing had 2-3 times the number of seeds in the zone of spring disking (0-9cm), and no-tillage had an extreme concentration of seeds in the top 1cm (>60%) and similar distribution to mouldboard ploughing below 3cm. Additionally, the soil seedbank in the top 19cm was approximately 60% greater in no-till and chisel ploughing than in mouldboard ploughing.

The implication for management is that the seedbank may be larger and more concentrated at the surface in a no-till field. Du Croix Sissons et al (2000) measured the mean recruitment depth of five common weed species in Manitoba. They found that mean recruitment depth was shallower in no-till fields compared to conventionally tilled fields. In both systems, weeds recruited from deeper in the soil profile after seeding. This is likely related to increasing soil temperature deeper in the soil as the season progresses.

Bullied et al. (2003) studied the recruitment timing of weeds from conventional and conservation tillage fields in Manitoba, Canada. They found that weeds recruited earlier in conservation tillage systems than in conventional tillage systems. Since soil moisture and soil temperature were not significantly different, it was concluded that the later recruitment in conventionally tilled fields was related to the lag in time from seed germination to seed recruitment due to the deeper seedbank in the conventional systems.

Thus, reduced or no-tillage fields may have greater weed pressure early in the season. In the beginning of the adoption of conservation tillage practices, herbicides were relied upon more heavily for weed control than they are now (MANDAK 1991). Studies have since shown that crop rotation has a bigger effect on weed levels than tillage

(Cardina et al. 2002) and crop rotations with high species diversity may offset the greater weed growth associated with conservation tillage systems (Kegode et al. 1999; Derksen et al. 1996).

2.3.6 Effect of Nitrogen on Weed Recruitment

2.3.6.1 Placement and Timing

Banding nitrogen fertilizer below the soil surface has been found to reduce weed recruitment and weed biomass and increase crop nitrogen uptake (Cochran et al.1990, Reinertsen et al. 1984, Blackshaw 2005). No-till would be expected to benefit more from banding because of the concentration of weed seeds on the surface (Yenish et al. 1992). However, Kirkland and Beckie (1998) reported that this was not always the case. The effect of banding on reducing weed growth is likely related to having the nitrogen very close to the crop early in the season and further away from the majority of weeds, giving the crop the advantage. Fields which have high levels of nitrogen, or have high amounts of nitrogen applied by any method, may not respond with less weed recruitment due to better nitrogen placement (Rasmussen 2002).

Whether nitrogen is applied in the fall or spring makes little difference in weed biomass or crop yield. However Blackshaw et al (2003) noted that with one exception spring applied fertilizer never resulted in increased weed biomass and never resulted in decreased crop yield

Surface applied manure or compost applied over many years was found to promote more weed growth than surface applied synthetic fertilizer (Blackshaw 2005). Weed biomass can be reduced by injecting manure, compared to surface application (Petersen 2003, Rasmussen 2002). This indicates weed growth can be inhibited by placing nitrogen below the surface regardless of source (inorganic vs. organic), but work would still need to be done to show whether the magnitude of the effect is similar.

2.3.6.2 Differential Response of Weeds and Crops

Studies have shown that the biomass accumulation of plant species to nitrogen application can vary dramatically. Blackshaw et al. (2003) tested different weed and crop species over a range of soil nitrogen levels to gauge their response to nitrogen. Shoot biomass increased from less than 25% to greater than 700%, whereas root biomass was not as dramatically influenced. Fifteen weed species were more responsive to nitrogen than wheat, while canola was found to be among the most responsive species to nitrogen. Weed species that tended to be known as strong competitors (redroot pigweed, wild mustard, and wild oat) showed some of the greatest responsiveness to nitrogen (Blackshaw et al. 2003). Other studies on corn have shown that as nitrogen is increased, corn is more competitive towards weeds (Evans et al. 2003). Therefore, knowing how responsive a crop and the dominate weeds are to nitrogen in a field can be used to give the crop a competitive advantage. For example, a wheat field with high wild oat numbers should not be over-fertilized, and the fertilizer should be carefully placed near the seed row, whereas a corn field with high green foxtail numbers should be given the maximum economic amount of fertilizer to allow the corn to out-compete the green foxtail (Cathcart and Swanton 2003).

Since flax was not included in either study it is hard to speculate how it would respond to N. Flax responds well to nitrogen but is a poor competitor to weeds (Flax Council of Canada 2005a). Poor flax competition against weeds is likely related to a low leaf area index which allows weeds to flourish (Flax Council of Canada 2005a).

Therefore, in a field situation, limiting nitrogen to only what the flax needs and keeping it as close as possible to the flax plants should increase the competitiveness of flax crops towards weeds.

2.4 Weed Management

2.4.1 Weed Control vs. Weed Management

Modern farmers tend to think of weeds as something to be controlled, whereas farmers in the past tended to think of weeds as something to be managed. Even the idea of managing weeds is a relatively new concept when viewed over all of human history. For example, British farmers only began to realize in the 18th century that proper weed control could increase crop production (Lockhart et al. 1990). Prior to this farms were small, intermingled, unfenced, and the focus was entirely on producing food for subsistence rather than for sale. Intensification and new techniques grew hand-in-hand with the Industrial Revolution. The three central features of crop production in Britain in this period were crop rotation, tillage, and seed cleaning (Lockhart et al. 1990)

The advent of herbicides in the mid-20th century changed all of this and spawned a new control mentality when dealing with weeds (Boyd 2003). It was believed that weeds could be eradicated from fields through the continuous use of pesticides. In some cases this led to even higher weed numbers due to selection for pesticide resistant weeds (Ghersa et al. 2000). There is no doubt that pesticides do work well, but the biggest criticism of pesticides is that once a producer has begun using them, it is very hard to stop because the farm and the management style are built around pesticides (Dent 2005). New pesticides must be continually developed and adopted to counter resistance from older formulations, and attempts at other strategies are usually met with limited short term success and economic benefit.

Agriculture has biased itself towards pesticide control in the past half-century, but it doesn't mean it cannot come back to a more balanced approach to weed management. Pesticides can be a part of a weed management strategy, but they should only be viewed as the last step when all other strategies have been implemented. Frick (1998) states that there are four components to a weed management system: Determine problem weeds on the farm, prevent new weed problems, manage the crop / weed environment in the crop's favour, and finally treat weeds directly (controlling those that escaped prevention and management).

2.4.2 Assessing Weed Problems

Assessing weed problems involves knowing the spatial distribution of weeds and their potential impacts (Frick 1998). A survey of Illinois farmers revealed that weed identification skills or knowledge of when certain weeds are a problem is not limiting farmers from assessing their fields (Czapar et al. 1997). More likely, it is the time involved in an already busy season and lack of motivation due to a perception of little or no economic value. Farmers often will have an intuitive sense of the weeds and problems in their field, but a systematic and detailed record of yearly weed problems will be helpful in better using cultural and pesticidal weed management techniques.

2.4.3 Preventing New Weed Problems

Farmers in Britain centuries ago identified clean seed as an essential component of good field husbandry (Lockhart et al. 1990). Certified seed has limits on the number of weed seeds and can limit the introduction of new weed species into fields. Farmers also relied on what they called "clean-up crops" in the rotation. These were crops that were conducive to weed control and helped to lower weed numbers for succeeding crops (Lockhart et al. 1990). Today, this would include intentionally sowing crops which have excellent herbicide programs. In the past decade herbicide tolerant crops have brought this to a new level by allowing farmers to spray non-selective herbicides in the crop season. Forages in a rotation have the potential to reduce weed numbers because of suppression, frequent mowing, and lack of soil disturbance (Entz et al. 2002; Frick 1998). In some cases, though, the use of forages merely selects towards those species which can tolerate mowing (Schoofs et al. 2005).

2.4.4 Managing the Crop / Weed Environment

Managing the crop / weed environment involves applying many management techniques that allow the crop to have the competitive advantage over the weeds (Frick 1998). Some techniques will have a long term effect (such as crop rotation and delayed seeding dates) and others will have a short term effect (high seeding rates, narrow row spacing, competitive crops, and competitive cultivars) (Nazarko et al. 2003; Frick 1998)

2.4.4.1 Crop Rotation

In numerous studies, crop rotation was found to have the greatest impact on weed management and yield among cultural weed control methods (Cardina et al. 2002; Kegode et al. 1999; Derksen et al. 1996). The main reason for crop rotation effectiveness against weeds is that it prevents the build up of one or a few particular weeds that can easily adapt to one or a few crops (Frick 1998). Crops that are established in the early spring will select for weeds that germinate early or even in the fall. Growing a crop that is seeded later will allow weeds to recruit and be destroyed before seeding. Conversely, after years of planting a late seeded crop, late emerging weeds will dominate and can be suppressed by planting a crop that establishes early and gets a head start on the weeds. Crop growth type will also effect weed management (Frick 1998). Fall seeded crops will be ahead spring emerging weeds, but will also select for fall germinating weeds. Perennial crops can actively cover the soil surface for a longer period of time than annual crops, but will select for weeds that can grow quickly and / or avoid destruction between cuttings.

2.4.4.2 Stale Seedbeds

Stale seedbeds are a variation on delayed seeding. Stale seedbeds involve preparing the seedbed as far in advance of seeding as possible to allow the weed flushes to emerge and be killed before seeding (Caldwell and Mohler 2001). Seeding is usually delayed as long as possible and soil disturbance is minimized when seeding to prevent stimulation of new weeds. Stale seedbeds are popular in vegetable or specialty crop production where herbicides or other control measures are lacking or are of limited effectiveness.

Johnson III and Mullinix Jr (2000) studied the effectiveness of stale seedbed preparation for peanut production using four different types of disturbance (power tiller, disk harrow, field conditioner and a sweep cultivator) to a depth of 7.6cm. They found no difference in mid-season weed counts among different treatments and the un-disturbed control. However, the weeds in the control were much larger and lowered peanut yields in two years out of three. They also found there were no differences in the number of passes for these tillage implements, indicating that it didn't matter how tillage was accomplished or how frequently it was performed, it only mattered that some tillage was used.

In conventional systems, the seedbank is distributed evenly through the soil profile; meaning that stale seedbed techniques may only influence one-quarter to one-third of the seedbank. No-till, on the other hand, has a very high proportion of seeds near the surface (Yenish et al. 1992) meaning that two-thirds to three-quarters of these seeds could be influenced. Disturbing the surface in a long term no-till corn soybean rotation increased weed recruitment three to six fold with a similar depletion of the seedbank (Mulugeta and Stoltenberg 1997). The authors concluded that with adequate rainfall this could be an effective technique to lower weed seedbank numbers in no-till.

2.4.4.3 Competitive ability

Crops vary in their competitive ability towards weeds. A general ranking from most competitive to least competitive would be barley > spring rye > wheat = oat > pea > potato > soybean > flax > bean (Frick 1998). Watson (2004) found that within a species (barley, *Hordeum vulgare*) cultivars can vary dramatically in their competitive ability.

Non-competitive crops and cultivars can be made more competitive by increasing plant density in the field. Stevenson and Wright (1996) compared three different seeding rates and three different row spacings of flax. Increasing seeding rate increased flax yield and decreased weed biomass, although there was no effect of plant population density on weed numbers. Under weedy (un-sprayed) conditions, the increase in flax yield was more pronounced. Therefore, increased seeding rates may be beneficial when reduced or no pesticides are used, but may not be necessary for maximum economic benefit when pesticides give complete or very good control. Reducing row spacing had a similar effect in the presence of weeds (weed density was unchanged and biomass went down), except that there was no yield advantage to narrowing rows.

2.4.5 Direct Treatment

Prior to herbicides, farmers relied on tillage for killing weeds out of both the cropping season and during crop growth. The mouldboard plough was used to loosen the soil to allow for seeding, to kill actively growing weeds, and to bury weed seeds deep in the soil profile (Lockhart et al. 1990). Turning the soil would also bring up weed seeds that were previously buried. Harrowing and cultivating could be used after ploughing to bury seedlings, cut seedlings off from their roots, pull perennial roots to the surface (where they would be desiccated by the sun), and stimulate growth of other seeds (Lockhart et al. 1990). While the crop was emerging, harrows could be used as long as the crop was more resilient than the weeds. Later on in the season, hand hoeing eliminated the late emerging weeds and weeds emerging within the row of the crop.

The drawback to tillage is that it leaves the soil vulnerable to erosion, rapid moisture loss, and rapid degradation of organic matter. No-till or minimum tillage agriculture was developed to address this need, but non selective herbicides are usually essential for this management system to work (MANDAK 1991).

In recent years there has been a renewed interest in pre-emergence and post-emergence tillage as a way to reduce herbicide use (Johnson 2001). Pre-emergence tillage, which tills after seeding but prior to emergence, is most successful when the weeds emerge prior to crop emergence, the crop is deep-seed, and the crop is competitive towards the weeds that will emerge with it (Johnson 2001). Post-emergence tillage has less success. Inter-row tillage suffers from weed escapes within the row (Johnson 2001) and harrowing can do more damage to the crop than the weeds if the crop is not hardy or in a weak life stage (Rydberg 1993). Post-emergence harrowing also suffers from lack of consistency in results (Rydberg 1993). Johnson (2001) reported that harrowing was able to select for weeds (e.g. wild oats in Saskatchewan) that were able to withstand harrowing year after year.

2.5 Research Rational and Objectives

Pesticides are effective in controlling weeds in agricultural systems, but they are perceived by many people to be hazardous to human health (Major 1992). Although pesticide formulations have less human toxicity, less environmental persistence, and greater efficacy for only the targeted pests than in the past, most are still are detrimental to human health and the environment (Pretty and Hine 2005). While organic farming proponents advocate the complete elimination of pesticides, the academic literature points to a more judicious use of pesticides, allowing farmers to become less dependent on them. By developing cropping systems around many weed management strategies, farmers can learn the cultural methods used by the generations before them that did not have pesticides at their disposal, as well as learn the new techniques developed by organic and environmentally conscious farmers of today.

No-till has gained popularity over the past few decades because of the effectiveness and economics of relying on pesticides for weed control over tillage. A no-till system can be superior to an organic system because tillage promotes more rapid erosion, soil moisture loss, and degradation of organic matter.

The objective of this study was to test a method for producing flax in a no-till system without the use of in-crop pesticides. The PFP (Pesticide Free Production) farming method was used as the model for input reduction. Since there has been success in stale seedbeds in conventional systems, the goal was to make this system work under a no-till system.

No-till land has a very shallow seedbank and research has shown that tillage can stimulate the growth of these weeds three to six fold (Mulugeta and Stoltenberg 1997). Since the weed seedbank is very close to the soil surface (Yenish et al. 1992), it was hypothesized that the same effect of increased weed recruitment would be found with light tillage rather than moderately deep tillage. Since nitrogen placed with the crop can help increase the crops competitive ability (Blackshaw 2005, Cochran et al.1990, Reinertsen et al. 1984), it was also hypothesized that placing nitrogen early would increase weed recruitment before seeding. Banding the nitrogen below the soil surface was chosen because broadcasting of nitrogen is generally considered to be a poor management practice in Western Canada, particularly in no-till, due to volatilization and immobilization (Malhi et al. 2001).

In this study, two levels of light tillage (rotary harrowing, 1-3cm deep, and seeder disturbance, 3-5cm deep) and early nitrogen placement were used with the goal of stimulating weed growth before the crop was planted. This was expected to reduce competition from weeds after the crop was planted. Consistent with the stale seed bed technique, disturbance was minimized during seeding and no additional disturbance occurred after seeding. Different combinations of frequency (fall and / or spring) and method (rotary harrow and / or seeder disturbance) were tested. Packing the surface after disturbance was also tested, as packing helps to increase recruitment through better seed / soil contact (Canola Council of Canada 2005). Pre-seed weed levels, post-seed weed levels, mid-season crop and weed biomass, and flax yield and quality measures were used to determine the success or failure of each method.

3.0 Materials and Methods

3.1 General

Field experiments were conducted at Agriculture and Agri-Food Canada's (AAFC) Brandon Research Centre experimental farm located 15 kms north of Brandon, MB in 2003/2004 and 2004/2005 and the University of Manitoba's field research station located near Carman, MB in 2004/2005. The Brandon experimental farm is located in the south-western part of the province with a Newdale Clay Loam soil (Grant, C.A. 2005). Brandon accumulates approximately 1600 Growing Degree Days (GDD) (Base 5˚C), averages 110 frost free days (MAFRI 1999) and receives approximately 474 mm of precipitation annually (Environment Canada 2004). Carman is located slightly more southerly in the Red River Valley with Rignold Loam soil (Mills and Haluschak 1993). Carman accumulates slightly more heat (1675 GDD), averages more frost free days (120) (MAFRI 1999), and receives more precipitation (542mm) annually than Brandon (Environment Canada 2004).

All sites were managed under a no-till system for at least three years prior to initiating the trials. The previous crop on each site was oats (*Avena sativa*). In both Brandon locations the oats were cut for green feed and at the Carman location the oats were harvested for seed with a chaff collector. Cutting for green feed kills weeds before they have a chance to produce viable seeds (AAFC 2004) and chaff collection prevents most weed seeds from being redistributed to the field (Shirtliffe and Entz 2005). In

Brandon weed re-growth after oat harvest was controlled with glyphosate (present as an isopropylamine salt) (675 g ai ha^{-1}).

3.2 Experimental Design

The first Brandon trial was established in the fall of 2003 while the second Brandon trial and the only Carman trial were established in the fall of 2004. Each trial was established as a randomized complete block design with four replications.

3.2.1 Treatments

A total of sixteen treatments (including checks) were tested at Carman and Brandon in 2005 while the Brandon 2004 trial had twelve treatments (Table 1). The additional four treatments in the second Brandon trial and the Carman trial were added after the Brandon 2004 trial had begun. Two checks were included: one conventionally managed treatment using pesticides for weed control (chemical check) and one managed without the use of chemicals (PFP check). Rotary harrow treatments included PFP plus fall rotary harrow (packed and not packed), fall and spring rotary harrow (packed and not packed), and spring rotary harrow (packed and not packed). A Phoenix Rotary Harrow[1] (driven at 13 km/h) 12’ double 3-point hitch model was used for the rotary harrow treatments. Packing was done with a coil packer pulled behind a tractor after rotary harrowing was done. Seeder disturbance included fall rotary harrow plus spring seeder disturbance and seeder disturbance alone. The early nitrogen treatments were embedded in the seeder disturbance treatments to account for the additional effect of disturbing the

[1] Phoenix Rotary Equipment Ltd., 401 18th Avenue, Nisku, AB, Can.

Table 1. List of treatment and descriptions used at all site years in the trial plus specific treatments measured for weed recruitment timing (Weed), soil temperature (Temp.), and soil moisture (Mois.).

Weed	Temp.	Mois.	Seeding	Description
*			Early	Chemical Check
*			Late	Chemical Check
*	*	*	Early	PFP Check
*	*	*	Late	PFP Check
*	*	*	Early	PFP + Fall RH
*	*	*	Late	PFP + Fall RH
			Early	PFP + Fall RH + Pack
			Late	PFP + Fall RH + Pack
*	*	*	Late	PFP + F&SRH
*			Late	PFP + F&SRH + Pack
			Late	PFP + Spring RH
			Late	PFP + Spring RH + Pack
*			Late	PFP + SD + Early N
*	*	*	Late	PFP + SD
*			Late	PFP + Fall RH + SD + Early N
*			Late	PFP + Fall RH + SD

Notes: PFP = Pesticide Free Production; RH = Rotary Harrow; F&SRH = Fall and Spring Rotary Harrow; SD = Seeder Disturbance. N = Nitrogen.
Treatments not measured for weed recruitment timing were not included in the Brandon 2004 trial.

surface. The first four treatments (chemical check, PFP check, and PFP plus fall rotary harrow (packed or not packed)) were duplicated with an early seeding date

3.2.2 Schedule of Operations

In the fall, tame oats (AC Assinobia) were broadcast at 50 kg ha^{-1} to act as a weed in all PFP plots (Table 2). No oats were applied to the chemical checks. On the same day certain plots were rotary harrowed and some were packed. Just prior to fall freeze up trifluralin (5% w/w) was applied to the chemical control plots at a rate of 1.1 kg (a.i.) ha^{-1} using a Valmar dry granular spreader.

The rotary harrowing, seeder disturbance, and early nitrogen treatments were applied on certain plots as early as the soil could be worked in spring. The early seeding date was chosen according to general agronomic recommendations. Flax can be seeded as early as possible because it can withstand spring frosts, even down to -3°C (Flax Council of Canada 2005a). In all site years the early-seeded flax was planted as soon as the ground was suitable for planting (Table 2). At the Brandon 2004 site over 500 mm of snow fell just after the pre-seed weed counts were completed. No weed growth was recorded in the eight days before the plots could be seeded so a re-count was not necessary. The late seeding date was chosen in order to maximize both weed growth and yield. Typically flax yields decrease 7%, 29%, and 52% when planted June 1st, June 10th, and June 20th, respectively (Flax Council of Canada 2005a). Therefore a target of June 1st was set for seeding the late-seeded plots (Table 2).

AC Lightning flax was planted at 60 kg ha^{-1} using a Conserva-Pak^{TM} seeder at 225 mm row spacing in Brandon and an R-Tech “Jethro” seeder at 200mm row spacing in

Table 2. Operation details dates for each site year over course of study.

Operation	Brandon 2004	Brandon 2005	Carman 2005
Oats cut for greenfeed / harvested	15-Aug-03	20-Sep-04	18-Sep-04
Tame oats spread	16-Sep-03	23-Sep-04	30-Sep-04
Fall rotary harrowing	30-Sep-03	23-Sep-04	30-Sep-04
Trifluralin applied to chemical checks	29-Oct-03	7-Nov-04	28-Oct-04
Spring light tillage and early nitrogen	22-Apr-04	20-Apr-05	19-Apr-05
Weed counts - early seeding	10-May-04	10-May-05	13-May-05
Early seeding	18-May-04	12-May-05	16-May-05
Weed counts - late seeding	2-Jun-04	30-May-05	31-May-05
Late seeding	3-Jun-04	31-May-05	31-May-05
Weed counts - early seeding	14-Jun-04	13-Jun-05	15-Jun-05
Early seeded checks sprayed	16-Jun-04	16-Jun-05	16-Jun-05
Weed counts - late seeding	28-Jun-04	24-Jun-05	23-Jun-05
Late seeded checks sprayed	28-Jun-04	25-Jun-05	23-Jun-05
Biomass - early seeding	3-Aug-04	19-Jul-05	22-Jul-05
Biomass - late seeding	10-Aug-04	29-Jul-05	3-Aug-05
All plots swathed	23-Sep-04	19-Sep-05	7-Sep-05
All plots harvested	7-Oct-04	21-Sep-05	12-Sep-05

Carman. This seeding rate is higher than required for attaining maximum yield under weed free conditions (Flax Council of Canada 2005a) but was chosen in order to maximize the competitive ability of flax (Stevenson and Wright 1996).

Due to a seeder error in 2005, only alternate rows emerged in the early-seeded plots in Brandon. Consequently stands were reduced to approximately half of the late-seeded plots. It was noted that in all of these plots the plants compensated by tillering and still filled in the canopy (visual observation). This is consistent with agronomic information provided by the Flax Council of Canada (2005a).

All plots received 70 kg ha^{-1} actual nitrogen in the form of urea and 25 kg ha^{-1} phosphate as mono ammonium phosphate. Fertilizer products were placed at the time of seeding with the seeder (25 mm to the side and 37.5 mm down from the seed with the ConservaPak seeder and 12.5 mm below with the R-Tech seeder). The exceptions were the two early nitrogen treatments where the nitrogen was placed approximately six weeks in advance of seeding at the same depth as the seed-placed fertilizer. At the time of seeding nitrogen was not applied to these particular plots so that all plots received the same amount of fertilizer. These rates were chosen according to current agronomic recommendations (Flax Council of Canada 2005a).

To remove weed growth prior to seeding, all plots received an application of glyphosate (present as an isopropylamine salt) at a rate 450 g ai ha^{-1} (except the late-seeded plots in Brandon 2004 which received a rate of 675 g ai ha^{-1} because of greater weed growth) sprayed with a water rate of 113 L ha^{-1}. The PFP system permits non-residual pesticides to be used prior to seeding. The chemical control plots also received an in-season treatment of sethoxydim (217 g ai ha^{-1}), clopyralid (present as acid) (103 g ai ha^{-1}), MCPA (present as 2-ethylhexyl ester) (576 g ai ha^{-1}), and adjuvant with surfactant blend 50% / solvent (petroleum hydrocarbons) 50% (1.0 L ha^{-1}) sprayed with a water rate of 113 L ha^{-1} at the 50 mm flax height stage.

Flax was swathed with a Versatile swather in Brandon and an R-Tech swather in Carman when the late seeded plots were mature (75% of bolls turned brown) (Flax Council of Canada 2005a). Due to a smaller swather in Carman only the centre of the plot was swathed in Carman whereas the entire plot was swathed in Brandon. Plots were harvested 1-2 weeks later with an MF-80XP combine at all site years when the swath was dry (Table 2).

3.3 Data Collection

3.3.1 Weed Recruitment

Weed recruitment timing was tracked at the Brandon sites only due to labour constraints at the Carman site (Table 1). Only the twelve original treatments were tracked at the Brandon sites. Meaningful conclusions would not be able to be reached with only one year of data from the additional four treatments added in 2005. Four 0.50m x 0.50m (0.25m^2) quadrats were laid down diagonally in each plot using a cable with equal spacings marked. Prior to planting, these quadrats had to be removed but were replaced immediately with the same cable or by marking with flags in order to be sure all quadrats were placed in the same spot. Recruitment was tracked from time of the spring operations (light tillage and early nitrogen) until flax was 50 mm tall.

Time zero was set to be the day rotary harrowing and nitrogen application occurred. No weed recruitment had begun prior to time zero. Starting at time zero, weeds were marked every 50-100 growing degree days (GDD's) (base 0°C) with coloured chicken banding rings or nickel-sized elastics. Each colour was unique to the day the rings or bands were laid and did not injure or impede growth of the weeds. Each weed species was identified and the number in each colour was recorded which allowed comparison of the recruitment of weed species over time in each of the twelve treatments recorded.

3.3.2 Weed Counts

Weed counts were completed for all treatments at all site years in the pre-seed and post-seed period. The pre-seed period was defined as the time from the spring operations (light tillage and early nitrogen) until seeding, while the post-seed period was defined as the time from seeding until in-crop spraying on the chemical weed control check plots (50 mm flax height) (Table 2). For the Brandon sites, weed recruitment tracking data was totaled across days prior to seeding and after seeding for the twelve treatments that were tracked for weed recruitment timing.

3.3.3 Weed and Crop Biomass

Weed and crop biomass was estimated just before the completion of flowering (growth stage number nine) (Flax Council of Canada 2005a). A biological stage was chosen so that both early and late-seeded treatments could be compared. The quadrat locations used for weed counts were again used for biomass giving a total of 1.0 m^2. All plant matter was cut out of each quadrat, bulked into one bag per plot, and hand sorted into either crop or weeds before drying. All samples were placed in drying ovens and dried at 65˚C for three days and the dry matter weighed.

3.3.4 Yield and Seed Measurements

Harvested flaxseed was weighed immediately after threshing to determine a wet weight and then was placed on drying racks at 50˚C for three days. Grain was then weighed again for a dry weight to determine moisture at combining. Grain was cleaned using a Clipper Grain Cleaner[2] with a 4/64" x 1/2" slot on the top and a 4/64" hole on the bottom with wind set on the medium belt and shutters closed. Flax was weighed again to determine dockage. Thousand seed weight was determined by weighing one-thousand seeds counted by a seed counter [3]

3.3.5 Soil Temperature

Soil temperature was recorded in all site years with each rep having one of three different brands of sensors[4] . A small hole was dug with a spade shovel in the centre of the plot and the sensors were placed in the side of the wall 25 mm below the soil surface. This was to ensure that the soil directly above the sensor was un-disturbed. When the hole was re-covered, care was taken to ensure the surface cover was identical to the surrounding plot.

Because of equipment constraints only a limited number of the treatments were sampled for soil temperature (Table 1). The PFP check, PFP plus fall rotary harrow, PFP plus fall and spring rotary harrow and spring seeder disturbance were chosen for soil temperature assessment because they represented the four major soil disturbances present

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[2] M2BC, Blount/Ferrell-Ross, 785 So. Decker Dr., Bluffton, IN., U.S.A.)

[3] Model 850-2, International Marketing and Design Company , Suite 200, 13802 Lookout Road, San Antonio, TX U.S.A.

[4] HOBO® H8 Temperature Data Logger, Onset Computer Corporation, Bourne, MA, U.S.A.; StowAway TidbiT Temperature Data Logger, Onset Computer Corporation, Bourne, MA, U.S.A.; Thermochron® iButton Temperature Sensor, Dallas Semiconductor Corp. Dallas, Texas, U.S.A

(ranging from none to considerable, respectively). In addition, the early seeded PFP check and PFP plus fall rotary harrow treatments were measured. Each sensor was set up to record one measurement every hour. Due to problems with set-up of the sensors only one rep of temperature data was recorded at the Brandon 2004 site. In 2005 all sensors functioned properly. Before placement in 2005, all sensors were tested using a growth chamber that had fluctuating day and night temperatures to ensure they were all set up properly and recording accurately.

3.3.6 Soil Moisture

Soil moisture in the top 50mm of the soil surface was measured with a TRIME[5] is a hand-held unit capable of measuring volumetric soil moisture using TDR (Time Domain Reflectometry). The TDR unit was tested against oven-dried volumetric samples to ensure accuracy (Appendix 1). The PFP check (early and late-seeded), PFP plus fall rotary harrow (early and late-seeded), PFP plus fall and spring rotary harrow, and spring seeder disturbance treatments were the only plots measured due to equipment and time constraints (Table 1). Since the equipment was only available in Brandon, the Carman site was not sampled for soil moisture. Soil moisture was measured every 50 to 100 GDD's corresponding approximately to the days that weeds were marked.

3.4 Data Analysis

3.4.1 The MIXED Procedure

Only in recent years has it been possible to easily analyze data using mixed model methodology because of advances in software (The MIXED procedure, Statistical

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[5] Time Domain Reflectometry with Intelligent Micromodule Elements) Portable TDR Soil Moisture Meter (MESA Systems Co., Medifield, MA, USA

Analysis Software (SAS), SAS Institute, Cary NC, U.S.A., 1992) and machines capable of running computationally intensive programs (Moser 2004, Littell et al. 1998). The MIXED (Mixed Models) procedure is much more comprehensive and powerful than the GLM (General Linear Models) procedure because, among other things, it correctly handles fixed and random effects (Littell et al. 1996). The MIXED procedure was written from the beginning to handle random effects whereas the GLM procedure was written for fixed effects only and modified later.

Restricted maximum likelihood (REML) is used by the MIXED procedure rather than the usual analysis of variance (ANOVA) mean squares used in GLM (Spilke et al. 2005). REML in PROC MIXED will automatically compute the correct test statistics (Steel et al. 1997); which was not always the case in GLM, usually with no way of fixing the problem (Littell et al. 1998, Littell et al. 1996, Wolfinger and Chang 1995).

3.4.1.1 Repeated Measures

It is essential to use PROC MIXED for analyzing repeated measures data[6] because PROC GLM cannot account for the unique variance and covariance structures found in this type of data. Repeated measures will usually be more correlated within a subject (plot, animal) than between subjects and measurements taken closer in time are usually more correlated than measurements taken further apart (Littell et al. 1998, Wang and Goonewardene 2004). To analyze this type of data the covariance structure is first determined and then the data is analyzed (Littell et al.).

[6] The Canadian Journal of Animal Science no longer accepts publications that use GLM to analyze random effects or repeated measures data (Wang and Goonewardene 2004).

Running the data first with the unstructured (UN) covariance will produce a matrix that may show the best structures to use (Wang and Goonewardene 2004). Because of its highly complex structure UN may not run in which case MANOVA may also be used to produce the matrix. After eliminating structures that obviously would not fit the data, each structure should be run and the one giving the smallest test statistics should be used (with preference given to the least complex structure) (Wang and Goonewardene 2004).

3.4.2 Data Analysis

All data was analyzed using the PROC MIXED procedure of SAS (v8.02). The Default Degrees of Freedom (DDFM) was set to the Satterthwaite's approximation (Littell et al. 1996). Residuals were plotted to check for homogeneity and normality. Any data which did not fit this criteria for analysis were transformed and the method that produced the best improvement was used (log or square-root). Many sources state that count data will usually require a square-root transformation (Little and Hills 1978, Mead et al. 2003., Steel et al. 1997) and this was found to be the case for almost all count data (some needed no transformation).

Residuals were also inspected for outliers. In one case (pre-seed oat counts at the Brandon 2005 site year) an outlier corresponding to one particular day was identified and removed. Mead et al. (2003) note that detailed records should be kept to identify possible problems before looking at the data; this plot was noted in the field to have exceptional growth on the day that was later removed. A residual plot showed this plot to have 6-10 times the amount of oat recruitment than any other plots which in and of itself is an obvious outlier (Littell et al. 1998). Another advantage of the MIXED procedure is that it can handle random missing data whereas the GLM procedure will not use any of the data from a subject with one or more missing data points.

Repeated measures analysis was carried out as described above. In all cases the simplest covariance structure with the lowest test statistics was used. Soil temperature data was analyzed using the first order auto-regressive (AR(1)) structure. AR(1) assumes equal variances among measurements, decreasing correlation of measurements over time, and equally spaced time. Soil moisture and weed count data were analyzed using the spatial power (SP(POW)) structure. SP(POW) is a generalization of the AR(1) structure to allow for un-equally spaced time periods. Weed count data was transformed to meet the assumption of equal variance; soil temperature and soil moisture data did not need transformation.

All possible factors could not be included in this study due to space constraints and agricultural significance. For example, spring disturbance treatments would not be effective in stimulating weed growth when combined with early seeding because there would not be sufficient time for an effect to show. Therefore, contrast statements were created to test agriculturally significant effects (Figure 3) similar to the methods used by Grant et al. (2004) and Jiao et al. (2004). In the case of soil temperature and soil moisture, contrasts were modified accordingly because of fewer treatments being measured. Similar to the above mentioned work, contrasts were not orthogonal to each other. Steel et al. (1997) state: "It is up to the investigator to decide whether the contrasts are meaningful in terms of the nature of the treatments and whether this is what is wanted from the data" (p. 187).

<u>The Effect of Late Seeding</u>
Early vs. Late

Early	**Chemical Check**
<u>Late</u>	**<u>Chemical Check</u>**
Early	**PFP Check**
<u>Late</u>	**<u>PFP Check</u>**
Early	**PFP + Fall RH**
<u>Late</u>	**<u>PFP + Fall RH</u>**
Early	**PFP + Fall RH + Pack**
<u>Late</u>	**<u>PFP + Fall RH + Pack</u>**
Late	PFP + F&SRH
Late	PFP + F&SRH + Pack
Late	PFP + Spring RH
Late	PFP + Spring RH + Pack
Late	PFP + SD + Early N
Late	PFP + SD
Late	PFP + Fall RH + SD + Early N
Late	PFP + Fall RH + SD

<u>The Effect of Using Chemicals (Early)</u>
Early PFP's vs. Early Chemical Check

<u>Early</u>	**<u>Chemical Check</u>**
Late	Chemical Check
Early	**PFP Check**
Late	PFP Check
Early	**PFP + Fall RH**
Late	PFP + Fall RH
Early	**PFP + Fall RH + Pack**
Late	PFP + Fall RH + Pack
Late	PFP + F&SRH
Late	PFP + F&SRH + Pack
Late	PFP + Spring RH
Late	PFP + Spring RH + Pack
Late	PFP + SD + Early N
Late	PFP + SD
Late	PFP + Fall RH + SD + Early N
Late	PFP + Fall RH + SD

<u>The Effect of Using Chemicals (Late)</u>
Late PFP's vs. Late Chemical Check

Early	Chemical Check
<u>Late</u>	**<u>Chemical Check</u>**
Early	PFP Check
Late	**PFP Check**
Early	PFP + Fall RH
Late	**PFP + Fall RH**
Early	PFP + Fall RH + Pack
Late	**PFP + Fall RH + Pack**
Late	PFP + F&SRH
Late	PFP + F&SRH + Pack
Late	PFP + Spring RH
Late	PFP + Spring RH + Pack
Late	PFP + SD + Early N
Late	PFP + SD
Late	PFP + Fall RH + SD + Early N
Late	PFP + Fall RH + SD

Figure 3 (page 1 of 3). Contrast statements used in data analysis.
Notes: PFP = Pesticide Free Production; RH = Rotary Harrow; F&SRH = Fall and Spring Rotary Harrow; SD = Seeder Disturbance; N = Nitrogen.

The Effect of RH with Early Seeding
Early PFP vs Early Fall RH

Early	Chemical Check
Late	Chemical Check
Early	**PFP Check**
Late	PFP Check
Early	**PFP + Fall RH**
Late	PFP + Fall RH
Early	**PFP + Fall RH + Pack**
Late	PFP + Fall RH + Pack
Late	PFP + F&SRH
Late	PFP + F&SRH + Pack
Late	PFP + Spring RH
Late	PFP + Spring RH + Pack
Late	PFP + SD + Early N
Late	PFP + SD
Late	PFP + Fall RH + SD + Early N
Late	PFP + Fall RH + SD

The Effect of RH with Late Seeding
Late PFP vs. RH's

Early	Chemical Check
Late	Chemical Check
Early	PFP Check
Late	**PFP Check**
Early	PFP + Fall RH
Late	**PFP + Fall RH**
Early	PFP + Fall RH + Pack
Late	**PFP + Fall RH + Pack**
Late	**PFP + F&SRH**
Late	**PFP + F&SRH + Pack**
Late	**PFP + Spring RH**
Late	**PFP + Spring RH + Pack**
Late	PFP + SD + Early N
Late	PFP + SD
Late	PFP + Fall RH + SD + Early N
Late	PFP + Fall RH + SD

The Effect of Early Nitrogen
Early Nitrogen vs. No Early Nitrogen

Early	Chemical Check
Late	Chemical Check
Early	PFP Check
Late	PFP Check
Early	PFP + Fall RH
Late	PFP + Fall RH
Early	PFP + Fall RH + Pack
Late	PFP + Fall RH + Pack
Late	PFP + F&SRH
Late	PFP + F&SRH + Pack
Late	PFP + Spring RH
Late	PFP + Spring RH + Pack
Late	**PFP + SD + Early N**
Late	**PFP + SD**
Late	**PFP + Fall RH + SD + Early N**
Late	**PFP + Fall RH + SD**

The Effect of SD's
Late PFP vs. SD's

Early	Chemical Check
Late	Chemical Check
Early	PFP Check
Late	**PFP Check**
Early	PFP + Fall RH
Late	PFP + Fall RH
Early	PFP + Fall RH + Pack
Late	PFP + Fall RH + Pack
Late	PFP + F&SRH
Late	PFP + F&SRH + Pack
Late	PFP + Spring RH
Late	PFP + Spring RH + Pack
Late	**PFP + SD + Early N**
Late	**PFP + SD**
Late	**PFP + Fall RH + SD + Early N**
Late	**PFP + Fall RH + SD**

Figure 3 (page 2 of 3). Contrast statements used in data analysis.
Notes: PFP = Pesticide Free Production; RH = Rotary Harrow; F&SRH = Fall and Spring Rotary Harrow; SD = Seeder Disturbance; N = Nitrogen.

The Effect of Packing after RH
No-Pack vs. Pack

Early	Chemical Check
Late	Chemical Check
Early	PFP Check
Late	PFP Check
Early	**PFP + Fall RH**
Late	**PFP + Fall RH**
Early	**PFP + Fall RH + Pack**
Late	**PFP + Fall RH + Pack**
Late	**PFP + F&SRH**
Late	**PFP + F&SRH + Pack**
Late	**PFP + Spring RH**
Late	**PFP + Spring RH + Pack**
Late	PFP + SD + Early N
Late	PFP + SD
Late	PFP + Fall RH + SD + Early N
Late	PFP + Fall RH + SD

The Effect of Fall RH before SD
Fall RH + SD vs. No Fall RH + SD

Early	Chemical Check
Late	Chemical Check
Early	PFP Check
Late	PFP Check
Early	PFP + Fall RH
Late	PFP + Fall RH
Early	PFP + Fall RH + Pack
Late	PFP + Fall RH + Pack
Late	PFP + F&SRH
Late	PFP + F&SRH + Pack
Late	PFP + Spring RH
Late	PFP + Spring RH + Pack
Late	**PFP + SD + Early N**
Late	**PFP + SD**
Late	**PFP + Fall RH + SD + Early N**
Late	**PFP + Fall RH + SD**

The Effect of Eliminating Spring RH
Fall RH vs. Fall & Spring RH

Early	Chemical Check
Late	Chemical Check
Early	PFP Check
Late	PFP Check
Early	PFP + Fall RH
Late	**PFP + Fall RH**
Early	PFP + Fall RH + Pack
Late	**PFP + Fall RH + Pack**
Late	**PFP + F&SRH**
Late	**PFP + F&SRH + Pack**
Late	PFP + Spring RH
Late	PFP + Spring RH + Pack
Late	PFP + SD + Early N
Late	PFP + SD
Late	PFP + Fall RH + SD + Early N
Late	PFP + Fall RH + SD

The Effect of Elminating Fall RH
Fall & Spring RH vs. Spring RH

Early	Chemical Check
Late	Chemical Check
Early	PFP Check
Late	PFP Check
Early	PFP + Fall RH
Late	PFP + Fall RH
Early	PFP + Fall RH + Pack
Late	PFP + Fall RH + Pack
Late	**PFP + F&SRH**
Late	**PFP + F&SRH + Pack**
Late	**PFP + Spring RH**
Late	**PFP + Spring RH + Pack**
Late	PFP + SD + Early N
Late	PFP + SD
Late	PFP + Fall RH + SD + Early N
Late	PFP + Fall RH + SD

Figure 3 (page 3 of 3). Contrast statements used in data analysis.
Notes: PFP = Pesticide Free Production; RH = Rotary Harrow; F&SRH = Fall and Spring Rotary Harrow; SD = Seeder Disturbance; N = Nitrogen.

4.0 Results and Discussion

4.1 Weather in Study Years

The year leading up to the study (2003) was a very dry year with below average precipitation in almost every month of the spring and summer; precipitation in July was 7% of it's the long term average (Figure 4). Temperatures were average through most of the growing season with the exception of August which had a mean temperature nearly 4˚C above average. Because of low precipitation and high August temperatures, the soil was much drier than would normally be expected in the fall. It is under these conditions that plots were established and some treatments were applied in the fall of 2003.

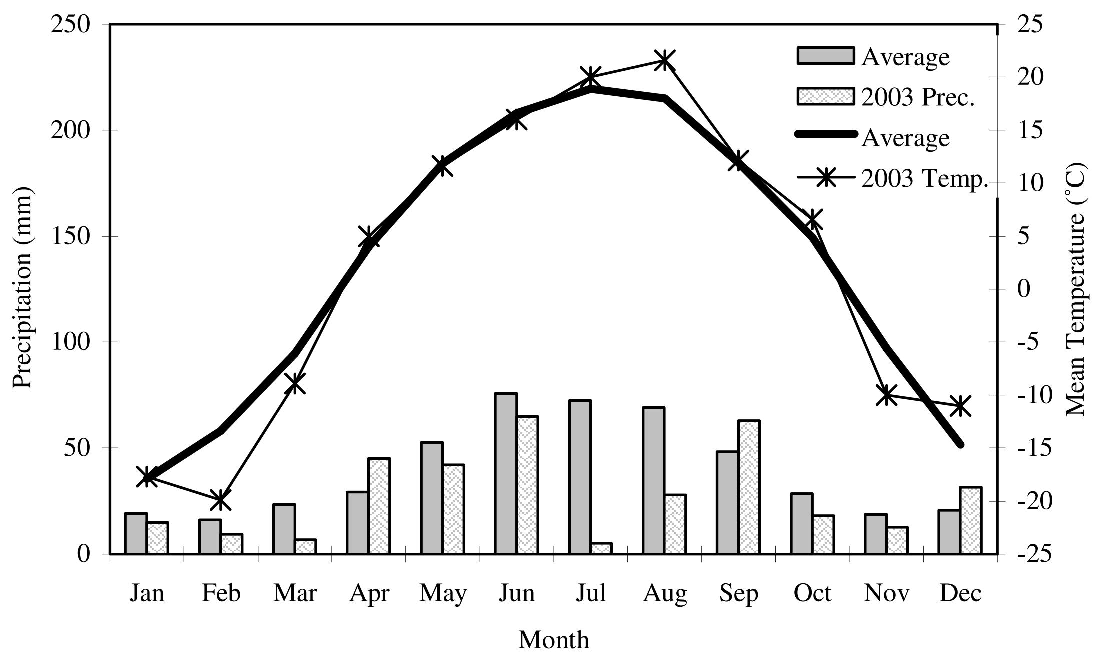

Figure 4. Long-term and seasonal weather data at Brandon 2003.
Source: Environment Canada (2004) and Environment Canada (2006)

The years 2004 and 2005 were marked by above normal moisture in the spring and early summer (Figures 5-8). In 2004, over 50 cm of snow fell on May 11 and 12.

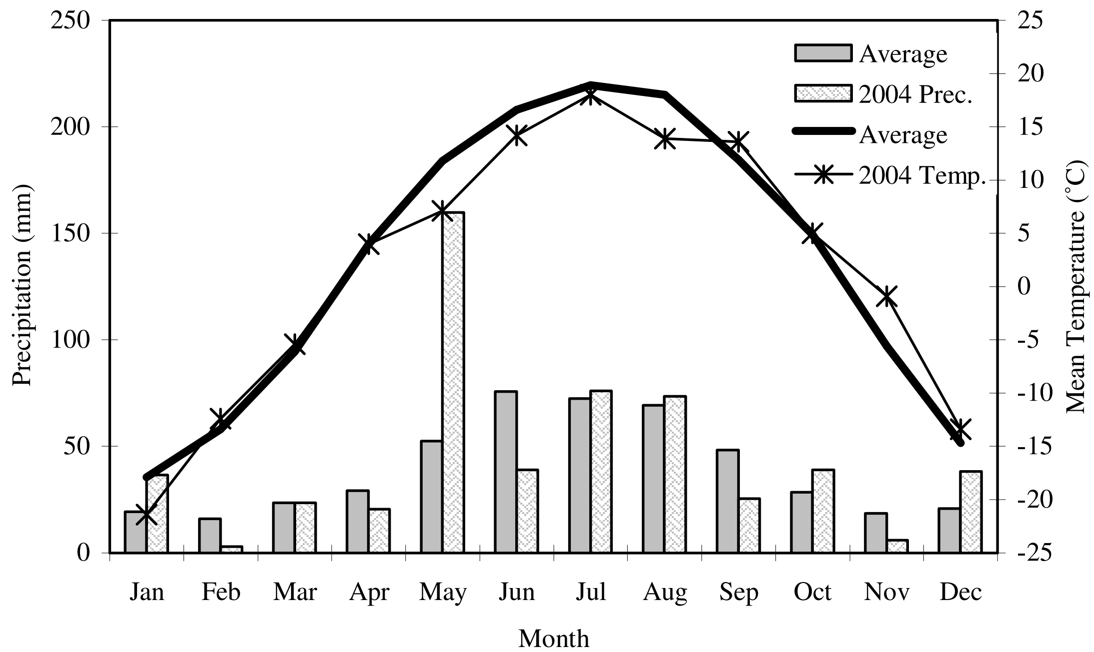

Figure 5. Long-term and seasonal weather data at Brandon 2004.
Source: Environment Canada (2004) and Environment Canada (2006)

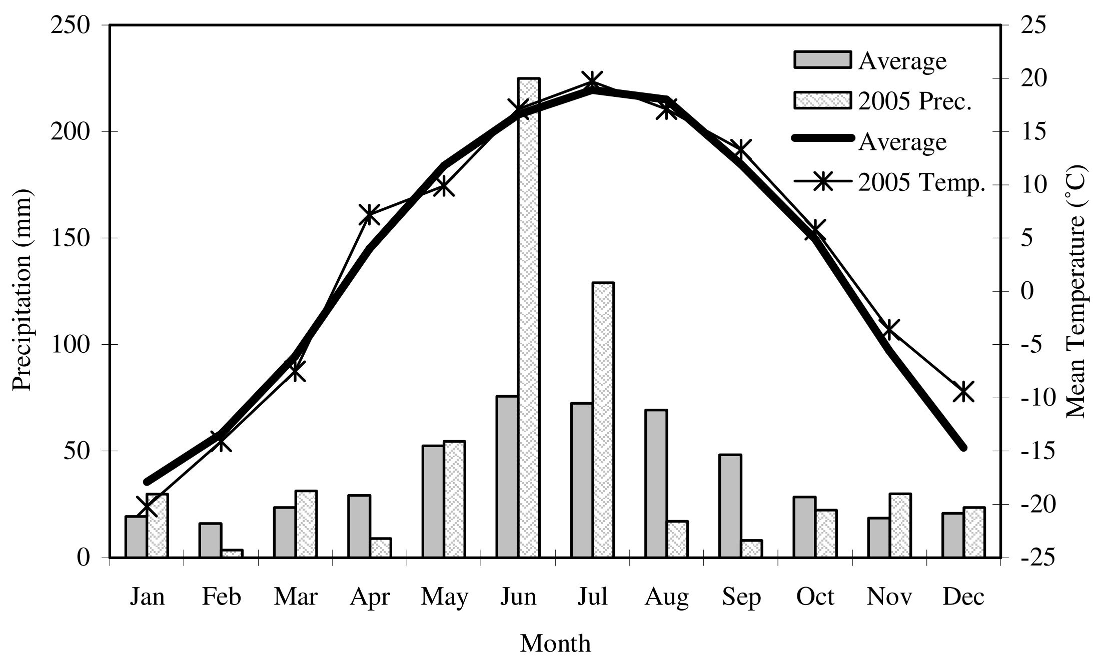

Figure 6. Long-term and seasonal weather data at Brandon 2005.
Source: Environment Canada (2004) and Environment Canada (2006)

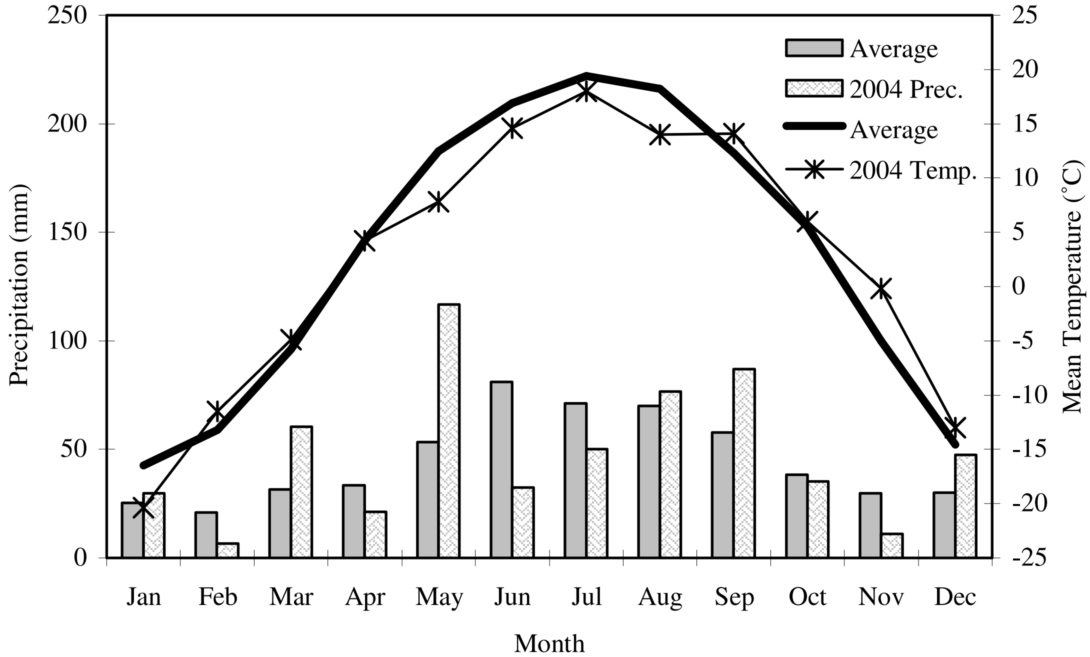

Figure 7. Long-term and seasonal weather data at Carman 2004.
Source: Environment Canada (2004) and Environment Canada (2006)

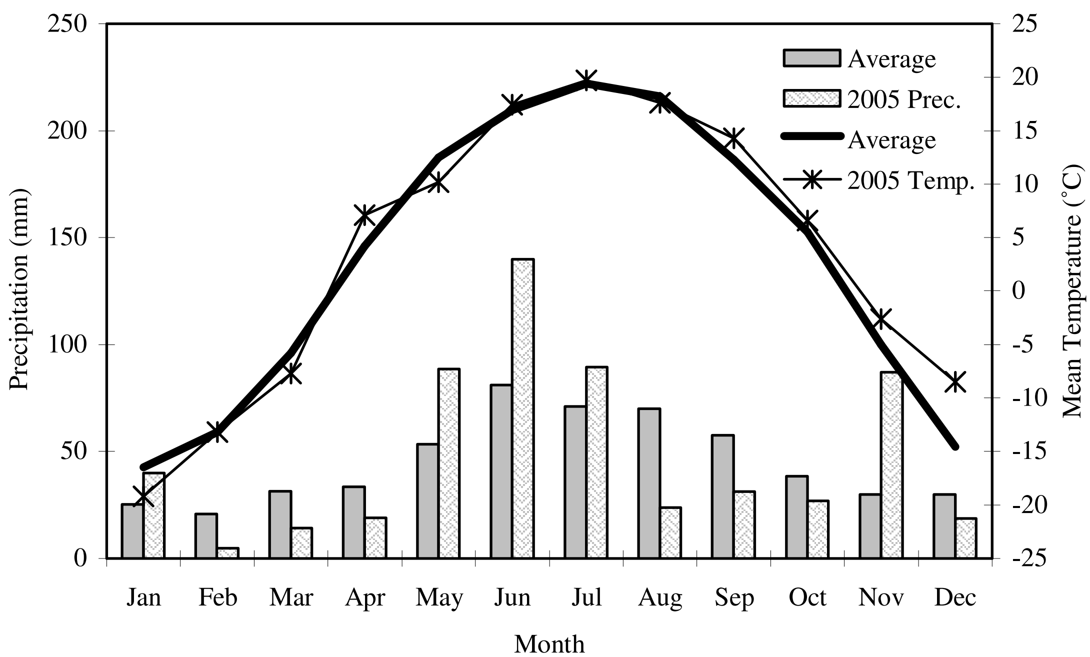

Figure 8. Long-term and seasonal weather data at Carman 2005.
Source: Environment Canada (2004) and Environment Canada (2006)

three times the average rainfall in June and nearly double the average rainfall in July. In 2005, Carman had 30-50% more rainfall than average during the same months.

In 2004, below average temperatures for nearly every month of the spring and summer (Figure 5) lead to crops not maturing before fall. Additionally, a severe frost hit most of the Prairies on August 20th, which stressed crops in the study area but did not kill the flax crop in the test plots. The 2005 growing season had near average temperatures for most of the spring and summer.

4.2 Flax Emergence

Average emergence at all test locations was above the 300 plants m^{-2} recommended by the Flax Council of Canada (2005a) (Table 3). Significant differences in plant establishment were observed only at the Brandon locations.

In both Brandon locations the early-seeded chemical check had significantly less emergence than the control. The late-seeded chemical checks were not affected in any site year. Plants in the early-seeded checks appeared slightly shorter than plants in all other treatments. However, no other visible damage or delays to flowering or maturity were noted. This is consistent with work by Nawolsky et al. (1992) who observed lower flax densities due to trifluralin injury.

The practice of applying trifluralin on the surface of a no-till field in the fall and not incorporating it is not registered in Canada or the U.S. (MANDAK 1997). This treatment was included in the trial because previous research has reported it to be effective (Kirkland 1996). Also, a weed-free check plot was needed in this study for comparison purposes. The reduction in stand observed in the trifluralin treated plots highlights that conventional systems do come with their own risks.

Table 3. Flax emergence values and contrast significance for all trial site years.

	Emergence (plants m^{-2})		
	Brandon 2004	Brandon 2005	Carman 2005 [1]
Early's vs Late's	n.s.	***	
Early's	426	214	385
Late's	446	396	339
Early PFP's vs Early Chem. Check	***	**	
Early PFP's	458	229	383
Early Chem. Check	361	170	392
Late PFP's vs Late Chem. Check	n.s.	n.s.	
Late PFP's	451	403	334
Late Chem. Check	438	376	352
Early Check vs Early Fall RH	n.s.	n.s.	
Early Check	454	235	375
Early Fall RH	462	227	386
Late Check vs RH's	n.s.	n.s.	
Late Check	437	376	343
RH's	443	403	342
Late Check vs SD's	n.s.	n.s.	
Late Check	437	376	343
SD's	431	396	373
Early Nitrogen vs. No Early Nitrogen	n.s.	***	
Early Nitrogen	423	355	367
No Early Nitrogen	439	437	379
Fall RH + SD vs. Spring SD only	**	n.s.	
Fall RH + Spring SD	456	381	391
Spring SD only	406	411	356
Pack vs No Pack	n.s.	n.s.	
Pack	432	405	336
No Pack	433	401	348
Fall RH vs Fall + Spring RH	n.s.	n.s.	
Fall RH	465	417	330
Fall + Spring RH	432	390	346
Fall + Spring RH vs Spring RH		n.s.	
Fall + Spring RH	n/a	390	346
Spring RH	n/a	403	350

Notes: Significance levels refer only to pair of values directly below.
*** p<0.01, ** p<0.05, * p<0.10, n.s. not significant.
All plots are Pesticide Free Production (PFP) managed except the Chemical Check.
Early’s = Early-seeded; Late’s = Late-seeded; RH = Rotary Harrow; SD = Seeder Disturbance.
[1] Overall test not significant.

A seeder error in 2005 in Brandon caused only alternate rows to emerge in the early-seeded plots. The seeder consists of 4 gangs of 4 openers giving a total of 16 rows being planted in one pass. The rows from the front two gangs did not emerge. The seed delivery system appeared to be in good working order which led to the speculation that the soil movement from the rear gangs covered the seed from two gangs just enough to prevent emergence. Upon further investigation, the front of the seeder was found to be slightly lower than the back which resulted in the front being planted deeper than the back. An adjustment was made which solved the problem before the late seeding date.

Because it took over two weeks to discover the problem, re-seeding was not an option for the early seeding dates. Since flax emerged in every other row (giving a new spacing of 450 mm) it was decided to leave the plots as they were because the flax would branch and cover over the plots (Flax Council of Canada 2005a). Alessi and Power (1970) found a yield advantage to 75 mm row spacing but little difference between 150 and 300 mm spacing under weedy conditions. Stevenson and Wright (1996) also found little impact of row spacing on flax yield when weeds were not controlled.

Stand densities reflected this loss of every other row showing approximately half the number of plants as the late-seeded plots (Table 3). According to the Flax Council of Canada (2005a) serious yield reductions do not occur until stands approach 100 plants m^{-2} in which case yield is expected to drop 20% therefore the average density of 214 plants m^{-2} was acceptable. Few other statistically significant effects were found for emergence at any site.

A higher than average seeding rate was used in the present study since dense plant stands are more competitive with weeds (Stevenson and Wright 1996). Only 50 to 60%

emergence is expected under normal field conditions (Flax Council of Canada 2005a) meaning 500 to 600 plants m^{-2} with a 60 kg ha^{-2} seeding rate (1000 seeds m^{-2}) should have been expected. In the present trial 35 to 45% emergence was attained. Since the flax is planted in rows and does not cover the entire soil area, the density within the row may be closer to 7000 to 10 000 seeds m^{-2}. At this high of a rate it is possible that all of the available seed emergence microsites were taken. Additionally, microsites that were biologically appropriate may have been eliminated because of the changing gaseous environment due to the germination of other species (Benvenuti 2003). This lower than expected germination percentage is consistent with Boyd and Van Acker (2004c) who found that as seeding rate increased proportional emergence dropped. Therefore, a higher seeding rate may not ensure greater competition of the flax plant from weeds due to microsite limitation.

4.3 Soil Moisture

4.3.1 Early-Seeded Plots

Soil moisture was not measured in Carman due to equipment and labour constraints and so discussions in the regard are restricted to only the effects at the Brandon locations. Very few soil moisture differences were observed between the undisturbed plot and the rotary harrowed plot for both years in Brandon (Figures 9 and 10). In both years, pre-seeding moisture levels followed a similar pattern. The rotary harrowed plot was generally drier than the undisturbed plot and the difference increased as time between rain events lengthened. In 2004, the plot land was recovering from nearly a year of below average precipitation (Figures 5 and 6). By May 10th the rotary harrowed plots had lost more moisture than the undisturbed plots showing that rotary

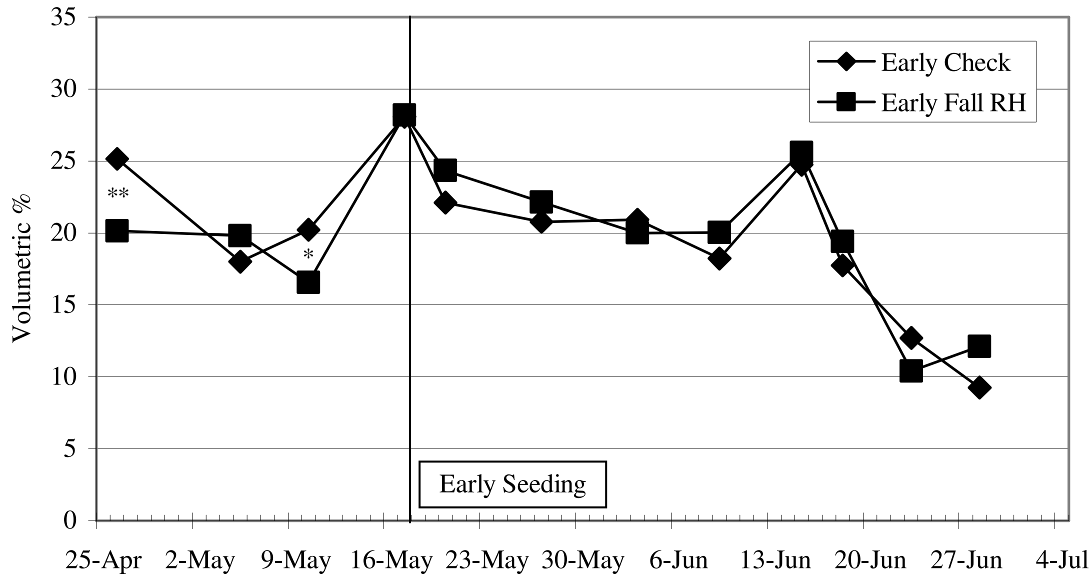

Figure 9. Volumetric soil moisture in the top 50 mm comparing the early check to the early fall RH at the Brandon 2004 location.
Note: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10. All plots are Pesticide Free Production (PFP) managed. Early = Early-Seeded; RH = Rotary Harrow.

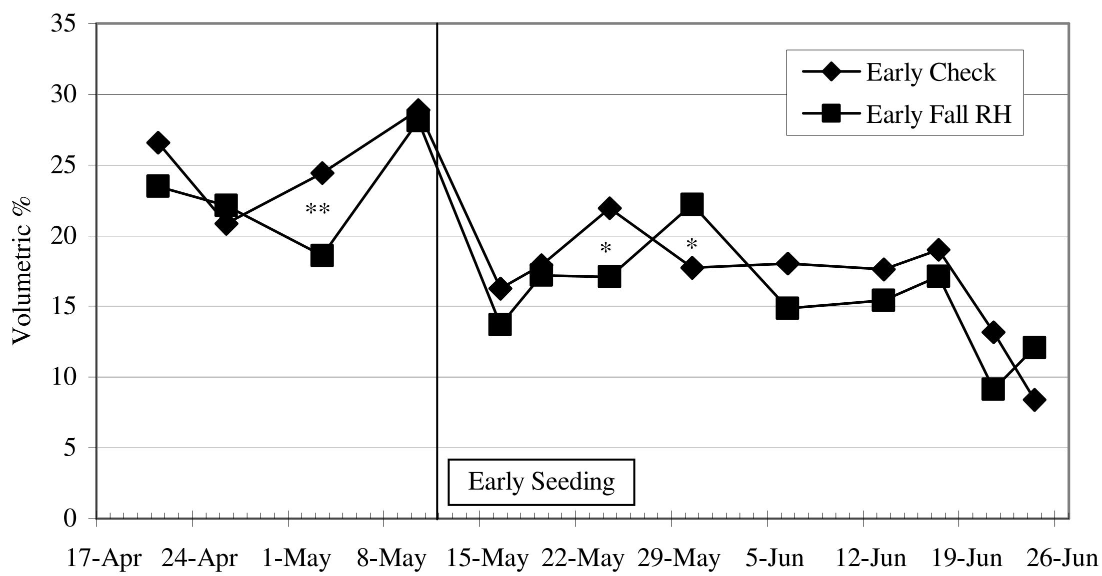

Figure 10. Volumetric soil moisture in the top 50 mm comparing the early check to the early fall RH at the Brandon 2005 location.
Note: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10. All plots are Pesticide Free Production (PFP) managed. Early = Early-Seeded; RH = Rotary Harrow.

harrowing will dry soil slightly, even though it provides minimal soil disturbance. A nearly identical pattern followed in 2005 with a decline in soil water volume due to rotary harrowing increasing as the time after a precipitation event increased. The rotary harrowing loosened the soil surface and presumably created more surface area which would allow more rapid soil drying (Gauer et al. 1982).

Post-seeding moisture levels were nearly identical for both treatments in both years. This is to be expected since the level of surface disturbance would now be identical and because of the excessive amounts of moisture that fell in each year after seeding (Figures 5 and 6).

4.3.2 Late-Seeded Plots

Very few soil moisture differences were observed between rotary harrowed plots and undisturbed plots for the late seeding date (Figures 11 and 12). In 2004, over 50 cm of snow fell on May 11^{th} and 12^{th} which replenished soil water. This event combined with frequent rainfall for the next month kept the soil close to field capacity. In 2005, a similar pattern was observed with average rains in May and excessive rains in June. These results suggest that in wet years, rotary harrowing will have little impact on soil moisture levels. This operation may cause drying of the soil surface in a dry year. More trials over varied environmental conditions are needed to verify this. Also tested at the late seeding date was the effect of one (fall only) or two (fall and spring) rotary harrow passes. Few significant differences were observed (Figures 13 and 14) Similar to the comparison of rotary harrowing to non-disturbance, moisture levels were similar over the course of the measurement period. Early in the season in both 2004 and 2005 before the spring precipitation began, the plots with two rotary harrow passes were significantly drier than undisturbed plots on at least one sampling date. As with the early seeding, all plots had similar levels of surface disturbance from the seeding operation and thus would have been expected to have similar moisture levels.

The seeder disturbed plots show significant soil moisture reductions compared to the check (Figures 15 and 16). This disturbance mixed the soil to 3-5 cm but reduced soil moisture levels by an average of 6.1% in 2004 and 5.9% compared to the check in 2005. Although the soil in the seeder disturbed plots would have had a lower bulk density due to tillage, the measurements were taken from the seed row area which would have been packed after the knife cut through the soil. A higher bulk density of the same soil will lower the volumetric water content due to more space being filled by air. In both years significant differences occurred during the entire pre-seed period and disappeared in the post-seeding period when the levels of disturbance would have been nearly equal. In a drier year, plots disturbed by the seeder would be the first to drop below the moisture threshold for weed recruitment and instead of working to enhance weed recruitment, as planned, could actually hinder weed recruitment of certain weed species.

4.3.3 Comparison of Early-Seeded and Late-Seeded Plots

Prior to first seeding date, early and late plots had similar levels of soil moisture (Figures 17 and 18). This would be expected because both seeding dates would have identical levels of disturbance at this point. In the period between early seeding and late seeding a distinct difference was observed between the two planting dates. This is similar to the difference between undisturbed plots and seeder-disturbed plots (discussed above). The early-seeded plots would be uniformly disturbed during this period whereas the majority of the late-seeded plots would be undisturbed. The differences in soil moisture

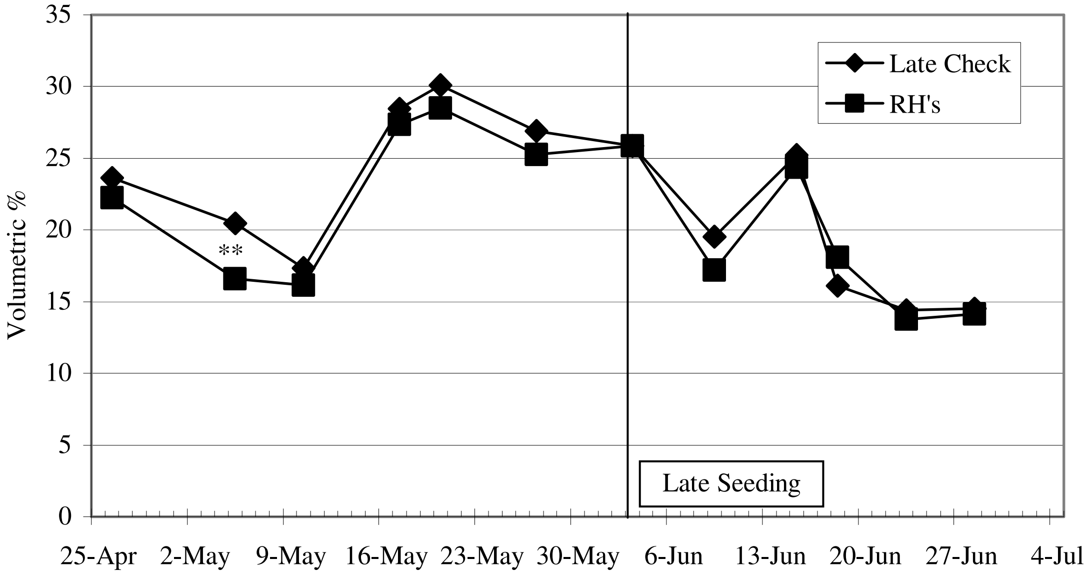

Figure 11. Volumetric soil moisture in the top 50 mm comparing the late check to the late RH's at the Brandon 2004 location.
Note: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10. All plots are Pesticide Free Production (PFP) managed. Late = Late-Seeded; RH = Rotary Harrow.

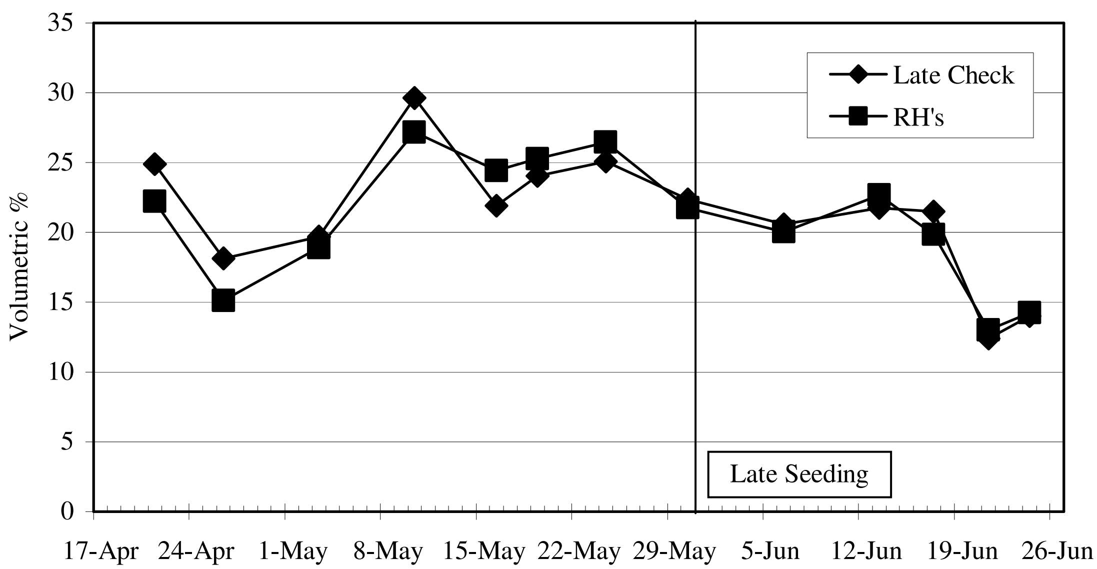

Figure 12. Volumetric soil moisture in the top 50 mm comparing the late check to the late RH's at the Brandon 2005 location.
Note: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10. All plots are Pesticide Free Production (PFP) managed. Late = Late-Seeded; RH = Rotary Harrow.

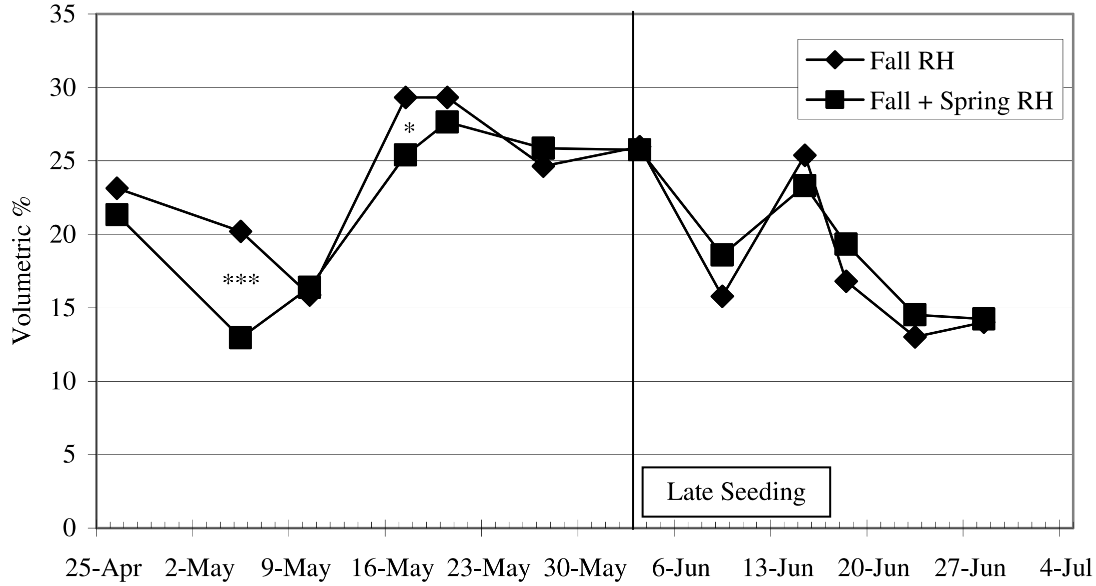

Figure 13. Volumetric soil moisture in the top 50 mm comparing the late fall RH to the late fall and spring RH's at the Brandon 2004 location.
Note: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10. All plots are Pesticide Free Production (PFP) managed. RH = Rotary Harrow.

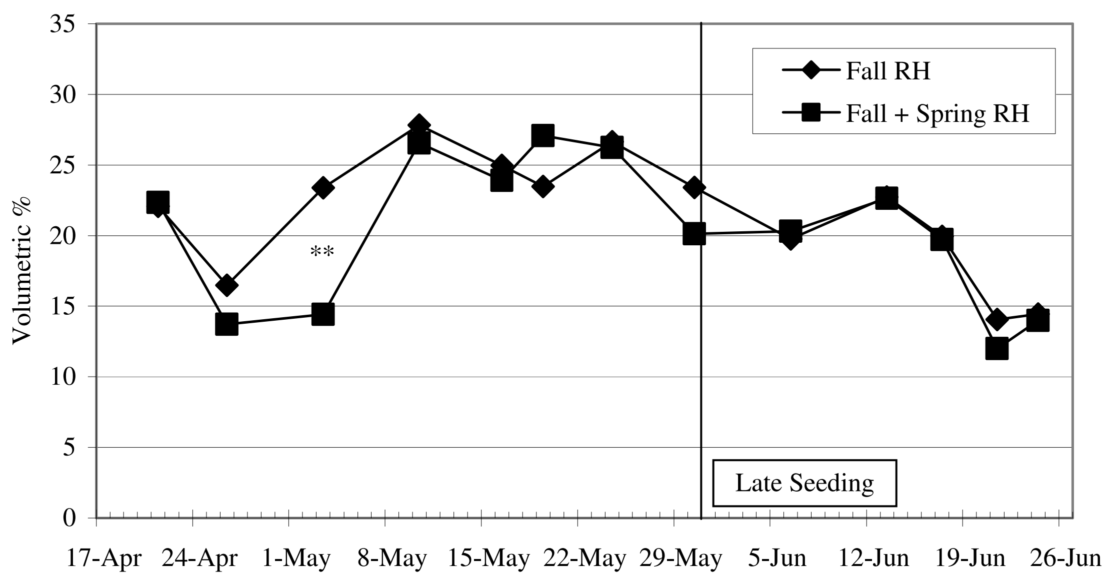

Figure 14. Volumetric soil moisture in the top 50 mm comparing the late fall RH to the late fall and spring RH's at the Brandon 2005 location.
Note: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10. All plots are Pesticide Free Production (PFP) managed. RH = Rotary Harrow.

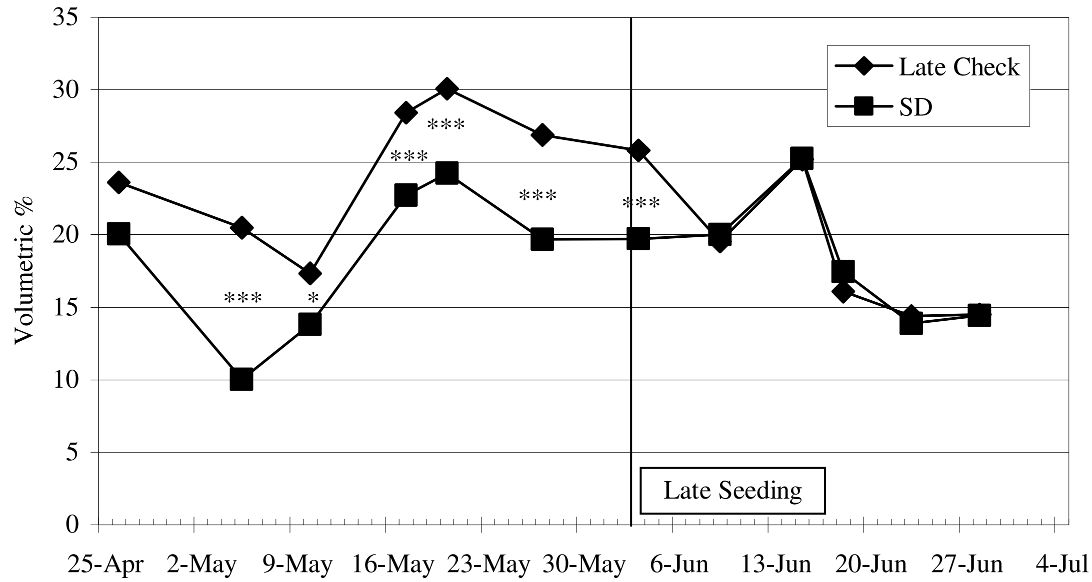

Figure 15. Volumetric soil moisture in the top 50 mm comparing the late check to the late SD's at the Brandon 2004 location.

Note: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10. All plots are Pesticide Free Production (PFP) managed. Late = Late-Seeded; SD = Seeder Disturbance.

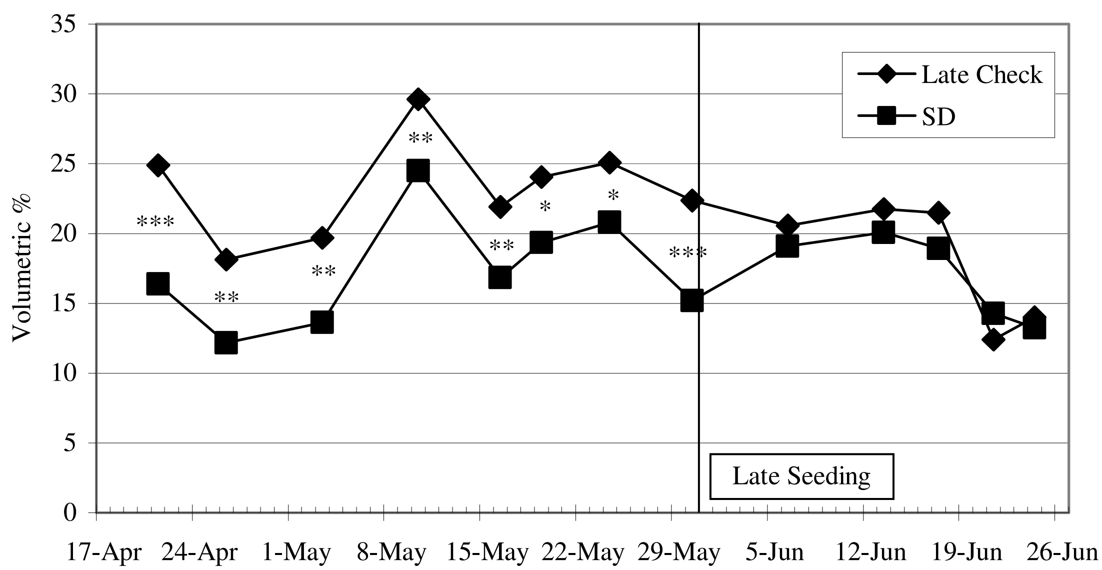

Figure 16. Volumetric soil moisture in the top 50 mm comparing the late check to the late SD's at the Brandon 2005 location.

Note: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10. All plots are Pesticide Free Production (PFP) managed. Late = Late-Seeded; SD = Seeder Disturbance.

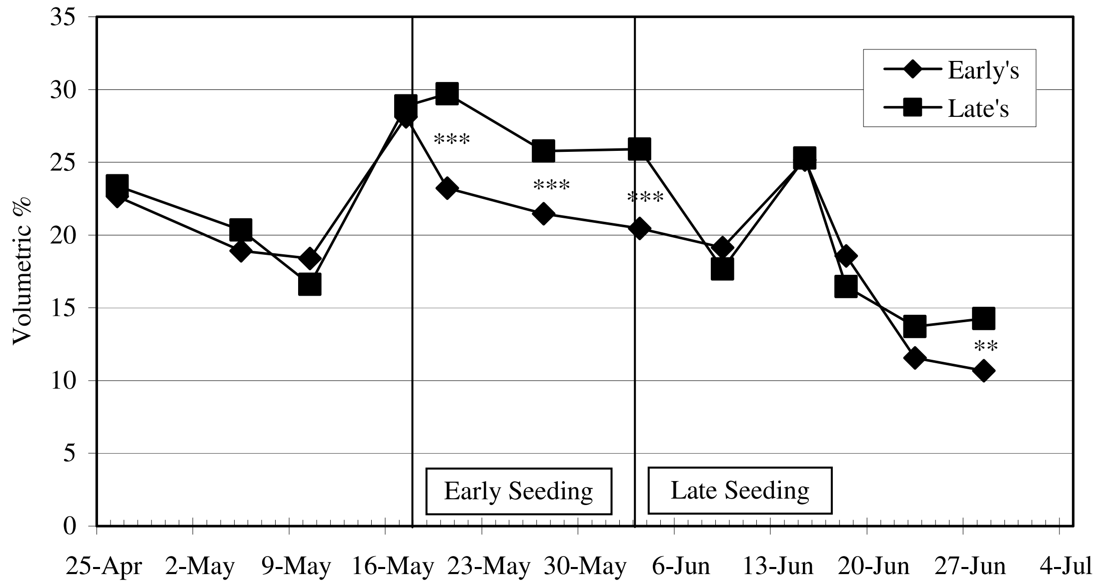

Figure 17. Volumetric soil moisture in the top 50 mm comparing the early-seeded to the late-seeded at the Brandon 2004 location.

Note: Significance levels refer only to pair of values on specific date; *** $p<0.01$, ** $p<0.05$, * $p<0.10$. All plots are Pesticide Free Production (PFP) managed. Early's = Early-seeded; Late's = Late-seeded;

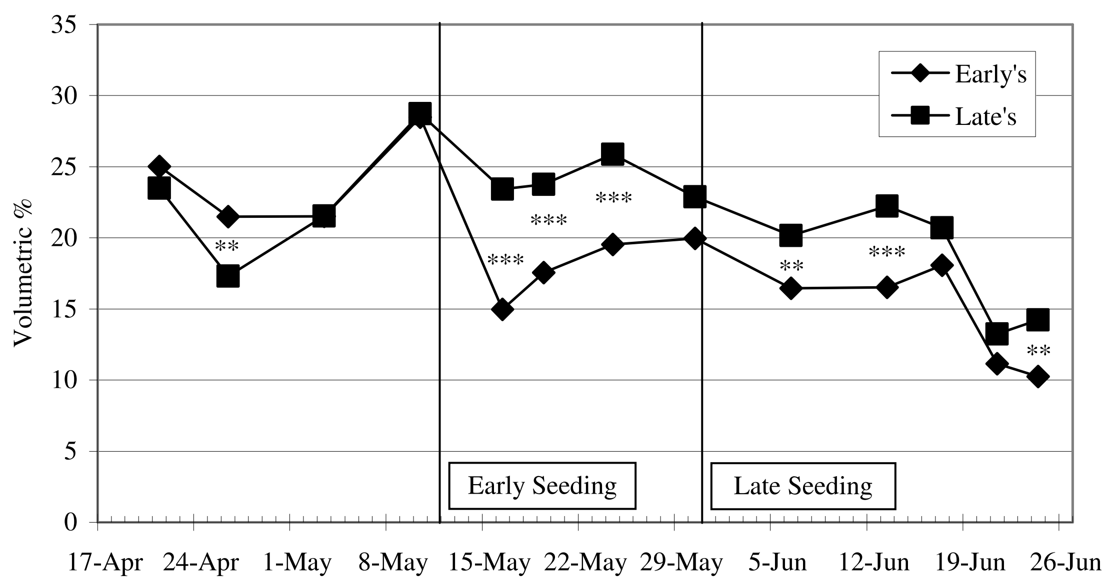

Figure 18. Volumetric soil moisture in the top 50 mm comparing the early-seeded to the late-seeded at the Brandon 2005 location.

Note: Significance levels refer only to pair of values on specific date; *** $p<0.01$, ** $p<0.05$, * $p<0.10$. All plots are Pesticide Free Production (PFP) managed. Early's = Early-seeded; Late's = Late-seeded;

between the early-seeded and late-seeded plots were similar to the differences between undisturbed plots and disturbed plots at 5.4% in 2004 and 6.0% in 2005. In 2004 the moisture levels converged after late-seeding whereas they did not converge completely in 2005 until the heavy rains began. The period leading up to late-seeding in 2005 was much drier than in 2004 which likely caused the lower soil moisture levels in the early-seeded plots. In both years the moisture content of early-seeded-plots dropped significantly compared to the late-seeded plots on the last measurement day which is likely related to the flax of the early-seeded plots extracting more moisture from the soil as compared to the late-seeded plots.

4.3.4 Moisture Limitations on Weed Recruitment

Only one treatment (seeder disturbance) showed consistent significant effects on soil moisture. Because it lowered soil moisture it would be more likely to hinder weed emergence than enhance it. Considering the wetter than normal year it is useful to evaluate whether moisture was ever limiting to weed emergence throughout the weed recruitment period.

Work on a clay soil in Southern Manitoba by Boyd (2005) shows that an osmotic potential of -0.1MPa corresponds to approximately 12% gravimetric moisture (unpublished). Depending on bulk density this could correspond to approximately 15 to 18% volumetric moisture. Work by Willenborg et al. (2005) shows that an osmotic potential of -0.2 MPa reduces oat germination to 97% of that under no water stress and Boyd and Van Acker (2003) cite work from many sources that shows a 33% decline in wild oat recruitment at an osmotic pressure of -1.2MPa. Boyd and Van Acker (2003) also cite sources that state that the beginning of the decline in recruitment of green foxtail only begins at -0.65MPa. Therefore setting the threshold for recruitment decline at 15-18% would safely allow for identifying times when effects from treatments could lower weed recruitment. Ideally, relationships between water potential and soil moisture would have been created for each site but this was not possible due to limitations in time and resources.

As mentioned earlier, both 2004 and 2005 were significantly wetter than the long term average. It was not until mid to late June, when most of the weed recruitment was already completed, that soil moisture levels dropped below the 15-18% threshold for an extended period of time. In 2004 values fell below 20% for only two days prior to seeding and in 2005 this only occurred once. These observations suggest that moisture likely did not limit weed growth for most of the study time in either year. Had both years been drier, moisture might have played a role in recruitment.

There were few treatment effects on moisture and moisture was at a level that would not have limited weed recruitment. Therefore it appears that soil moisture cannot be used to explain any treatment differences in weed recruitment in the present study.

4.4 Soil Temperature

Because of temperature sensor problems referred to in Materials and Methods, only data from Brandon 2005 and Carman 2005 is presented. When daily temperatures were plotted according to measured treatments there was no more than one degree Celsius variation at any one time with a more typical variation of tenths of degrees (Figures 19 and 20). When comparing the seasonal average temperature between treatments both Brandon and Carman showed significant *statistical* differences (Table 4).

Disturbed plots (rotary harrow and seeder-disturbance) were cooler than undisturbed plots. Two passes of the rotary harrow was cooler than one pass of the rotary harrow. Late-seeded plots were slightly warmer than earlier plots which could be explained by most of them not being disturbed until the end of May. This is consistent with Gauer et al. (1982) who found that no-till ground with the straw mulch removed held more heat than tilled ground with no mulch. Although these plots had some residue from the previous year there was very little left on the surface by the spring. Fall rotary harrowing did not have an effect in the early-seeded plots which is likely attributable to a very short time between thaw and seeding.

Although statistical differences were evident between contrast pairs, the magnitude of the difference was very small. This is mainly due to the fact that over sixty measurements were used for each average (two months of data) allowing detection of differences that are unlikely to statistically significant. Most comparisons differ by only 0.2 to 0.3˚C per day with the largest difference being just under 0.5˚C per day. This is similar to Reid and Van Acker (2005) who found only a 0.1˚C difference between tilled and untilled treatments.

Growing Degree Days (GDD) were calculated from the soil temperature data. Brandon 2005 averaged 12.1 GDD per calendar day and Carman 2005 averaged 12.5 GDD per calendar day from spring disturbance to the 5 cm stage of flax in the late-seeded plots. With differences averaging approximately 0.2 to 0.3 GDD per calendar day warmer treatments tested in this study would take on average approximately 40 to 60

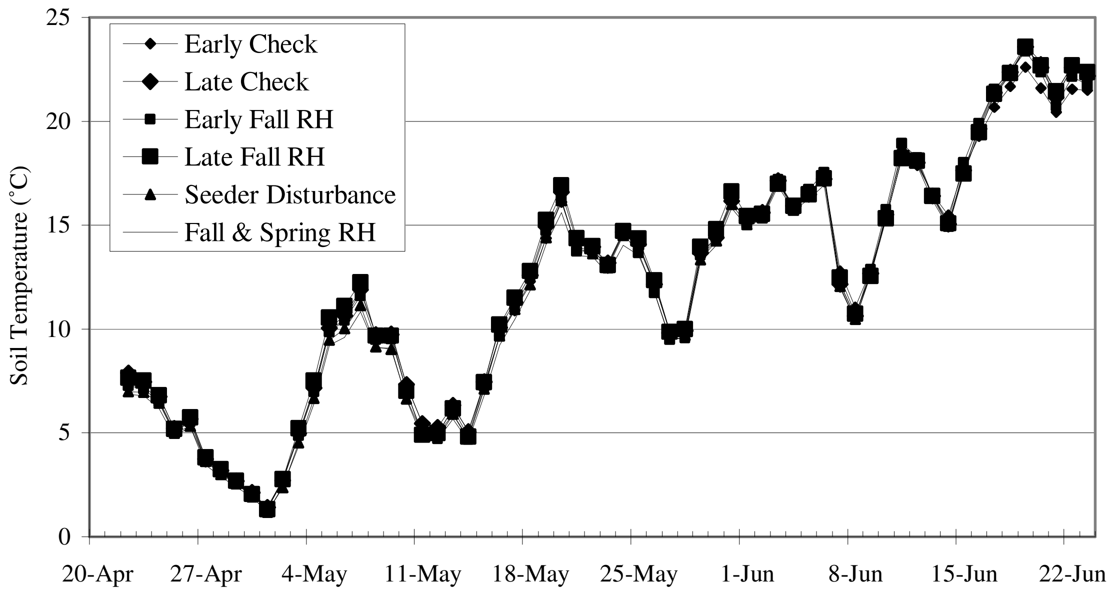

Figure 19. Average daily soil temperature 25 mm below soil surface by for the six measured treatments at the Brandon 2005 location.

Notes: All plots are Pesticide Free Production (PFP) managed.
Early = Early-seeded; Late = Late-seeded; RH = Rotary Harrow.

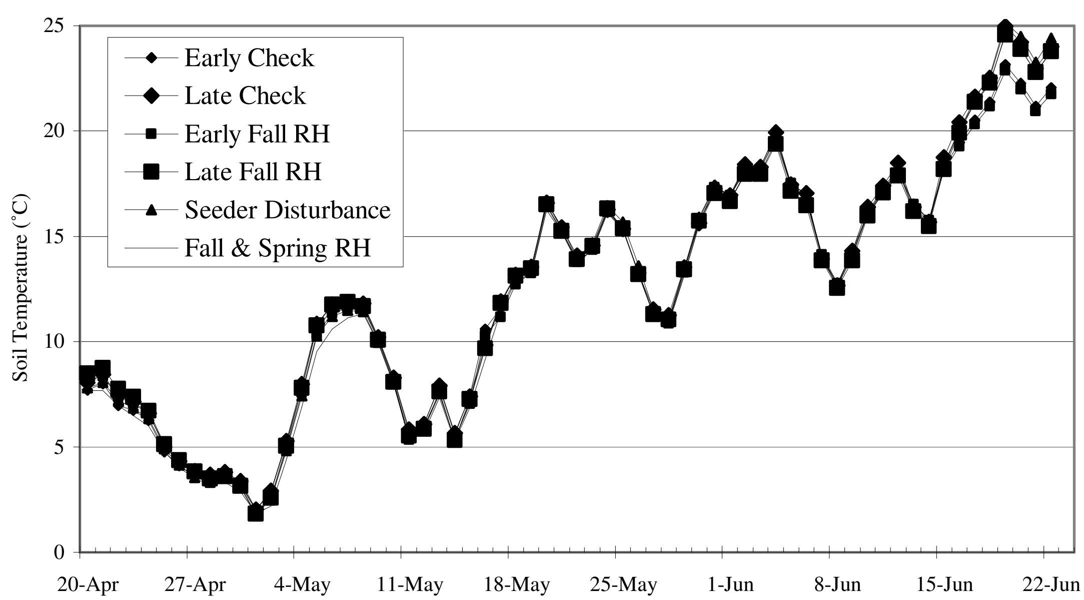

Figure 20. Average daily soil temperature 25 mm below soil surface by day for the six measured treatments at the Carman 2005 location.

Notes: All plots are Pesticide Free Production (PFP) managed.
Early = Early-seeded; Late = Late-seeded; RH = Rotary Harrow.

Table 4. Average daily soil temperature 25 mm below soil surface and contrast significance from spring disturbance treatments 2005 (April 22nd to June 27th in Brandon and April 20th to June 22nd in Carman).

	Soil Temperature (C)	
	Brandon 2005	Carman 2005
Early's vs Late's	***	***
Early's	12.09	12.40
Late's	12.27	12.63
Early Check vs Early Fall RH	n.s.	*
Early Check	12.08	12.44
Early Fall RH	12.10	12.36
Late Check vs RH's	***	***
Late Check	12.24	12.71
RH's	12.06	12.43
Late Check vs SD	***	***
Late Check	12.24	12.71
SD	12.02	12.57
Fall RH vs Fall + Spring RH	***	***
Fall RH	12.30	12.54
Fall + Spring RH	11.82	12.33

Notes: Significance levels refer only to pair of values directly below.
*** $p<0.01$, ** $p<0.05$, * $p<0.10$, n.s. not significant.
All plots are Pesticide Free Production (PFP) managed
Early's = Early-seeded; Late's = Late-seeded; RH = Rotary Harrow; SD = Seeder Disturbance.

calendar days to enhance crop development by one calendar day. In other words, warmer treatments would be only one to one-and-one-half days ahead of cooler treatments in terms of heat accumulation over the entire course of the major weed recruitment.

Because there was little difference in heat accumulation over the season and on individual days it can be concluded that the treatments did not have an effect on soil temperature. This means that soil temperature will likely not be able to explain any differences in weed recruitment among treatments.

4.5 Weed Recruitment

Two weed species, wild oat (*Avena fatua*) and green foxtail (*Setaria viridus*), dominated the study sites. These two weeds comprised nearly 82% of the weed species in Brandon 2004, over 94% of the weed species in Brandon 2005 and over 41% of the weed species in Carman 2005. According to Leeson et al. (2002) these two weed species are the two most common weeds found in Manitoba fields. Repeated measures analysis was only performed on late-seeded plots because of insufficient data before early seeding. Green foxtail was only analyzed for the post-seeding date because recruitment only began in the last measurement period before seeding.

4.5.1 Pre-Seed Weed Recruitment

4.5.1.1 Wild Oat

Early-seeded plots had significantly lower wild oat recruitment than late-seeded plots at all site years (Table 5). Within the early seeding date, rotary harrowing in the fall had a limited impact on wild oat recruitment. At the Brandon 2004 location, rotary harrowing resulted in slightly higher wild oat recruitment but this was not seen at the other two locations in 2005. This is what was expected due to the limited time for wild oat recruitment to occur prior to planting.

For both the early and late seeding dates, the chemical check had significantly lower wild oat density at the Brandon 2004 location only. The wild oat recruitment pattern for the late-seeded plots (Figure 21) shows that the trifluralin suppressed the beginning of wild oat recruitment by two weeks (May 5th vs. May 20th) and continued to suppress recruitment beyond that. The effect of the trifluralin on wild oat recruitment was not seen as distinctly at the 2005 locations (Table 5). This is confirmed by the recruitment pattern of the late-seeded checks and chemical checks at the Brandon 2005 location (the Carman location was not tracked for recruitment). The chart shows no difference in recruitment over the pre-seeding period (Figure 22).

In this study, the trifluralin was not incorporated into the soil because it is a no-till system (Kirkland 1996). While there is little published data on the efficacy of surface application of trifluralin, it is known to adhere strongly to soil organic and inorganic material and leaches very little (WSSA 2002). The year 2005 had near average (54 mm) amounts of precipitation in May compared to 2004 which had three times the long term average amount of precipitation (160 mm). One explanation for greater efficacy of the trifluralin on wild oats in 2004 is the greater precipitation which was able to bring the chemical into the proper area for wild oat recruitment impediment. The near average amount of precipitation in 2005 in May may not have allowed a similar movement the chemical down into the soil. These results underline that this system may not be effective for wild oat control under typical Manitoba conditions. Current labeling of trifluralin indicates only suppression of wild oat not control.

Within the late seeding date, both disturbance treatments (rotary harrow and seeder disturbance) increased wild oat density over the control plot over all years. At the Brandon 2004 location the rotary harrow tripled wild oat recruitment whereas seeder disturbance doubled wild oat recruitment compared to the undisturbed check (Table 5). In both cases the difference was highly significant. At the Brandon 2004 location the bulk of wild oat recruitment began much earlier in the rotary harrowed plots compared to the undisturbed plots and greater recruitment was sustained until the last measurement day (June 2nd) (Figure 23). Greater recruitment did not begin as early in the seeder disturbed plots as compared to the rotary harrowed plots (Figure 25). The effect of rotary harrowing and seeder disturbance in late-seeded plots was evident again at the 2005 locations. However, absent or weak statistical differences may have been related to the lower overall wild oat numbers resulting in less powerful statistical tests. The recruitment patterns of the Brandon 2005 location (Figure 24 and 26) confirm that significant recruitment did occur on certain days for both rotary harrowing and seeder disturbed plots. Different from 2004, no advantage of early wild oat stimulation was seen with the rotary harrow in this year.

It is not known why the rotary harrow stimulated wild oat in 2004 but not in 2005. One explanation may be much higher wild oat populations in 2004 compared to 2005. The great amounts of moisture in 2004 may have contributed by keeping all of the potential microsites sufficiently moist. Additionally, because 2003 was a very dry year, greater numbers of wild oat seeds would lay dormant and not be recruited. This would allow the seedbank to grow to higher levels than would normally be expected. Because wild oat is a generalist species, it would grow as soon as conditions were met.

Another factor in the success of the rotary harrow may be its uniformity of disturbance compared to the seeder. The seeder will not be as uniform in disturbance because the knives that cut the soil for seed placement will disturb the soil greatly where they cut through and throw the soil over top of the surface in between the rows (Doan 2003). It is likely that the more uniform disturbance by the rotary harrow helped to increase the chance of seeds being placed in the proper microsite.

Across all years spring disturbance was superior to fall disturbance for increasing wild oat recruitment. For example, there was never an advantage of fall rotary harrowing

Table 5. Pre-seed wild oat density and contrast significance for all trial site years.

	Pre-Seed Wild Oats (plants m^{-2})		
	Brandon 2004	Brandon 2005	Carman 2005
Early's vs Late's	***	*	**
Early's	24	18	5
Late's	235	39	9
Early PFP's vs Early Chem. Check	**	n.s.	n.s.
Early PFP's	35	21	6
Early Chem. Check	3	10	2
Late PFP's vs Late Chem. Check	***	n.s.	n.s.
Late PFP's	307	36	9
Late Chem. Check	90	46	6
Early Check vs Early Fall RH	*	n.s.	n.s.
Early Check	14	29	2
Early Fall RH	56	17	7
Late Check vs RH's	***	n.s.	n.s.
Late Check	180	32	11
RH's	540	71	17
Late Check vs SD's	***	*	*
Late Check	180	32	11
SD's	349	75	22
Early Nitrogen vs. No Early Nitrogen	n.s.	n.s.	n.s.
Early Nitrogen	352	77	23
No Early Nitrogen	345	73	21
Fall RH + SD vs. Spring SD only	n.s.	n.s.	n.s.
Fall RH + Spring SD	329	82	19
Spring SD only	368	68	25
Pack vs No Pack	n.s.	n.s.	n.s.
Pack	607	68	17
No Pack	579	73	16
Fall RH vs Fall + Spring RH	n.s.	**	*
Fall RH	435	39	9
Fall + Spring RH	593	89	16
Fall + Spring RH vs Spring RH		n.s.	*
Fall + Spring RH	n/a	89	16
Spring RH	n/a	84	26

Notes: Significance levels refer only to pair of values directly below.
*** p<0.01, ** p<0.05, * p<0.10, n.s. not significant.
All plots are Pesticide Free Production (PFP) managed except the Chemical Check.
Early’s = Early-seeded; Late’s = Late-seeded; RH = Rotary Harrow; SD = Seeder Disturbance.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

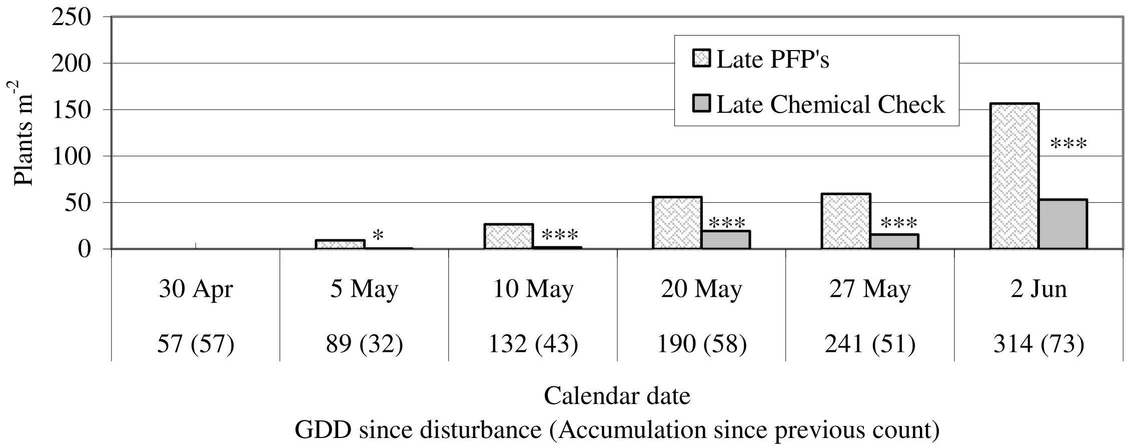

Figure 21. Pre-seed wild oat recruitment comparing the late PFP's to the chemical check at the Brandon 2004 location.

Notes: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10.
All plots are Pesticide Free Production (PFP) managed.
Each date represents new weeds emerged since the previous count. GDD's (Growing Degree Days, Base 0˚C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

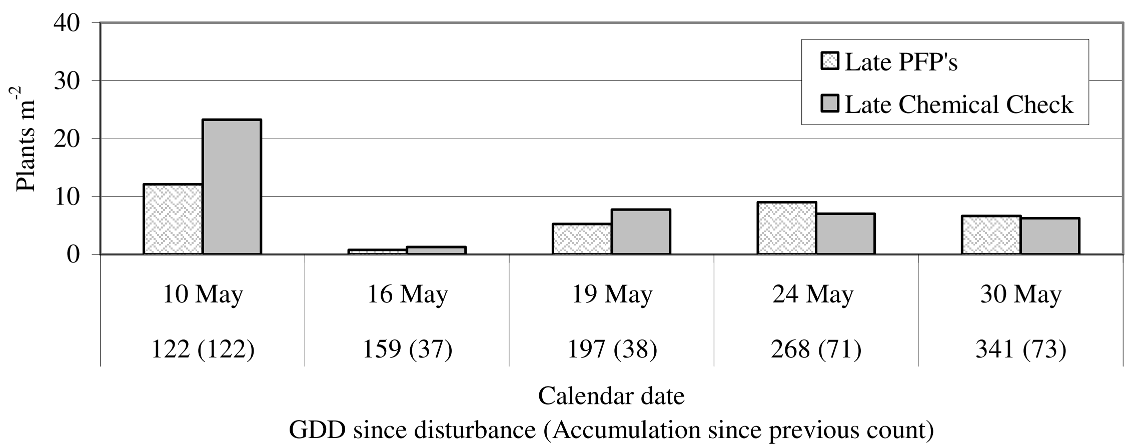

Figure 22. Pre-seed wild oat recruitment comparing the late PFP's to the chemical check at the Brandon 2005 location.

Notes: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10.
All plots are Pesticide Free Production (PFP) managed.
Each date represents new weeds emerged since the previous count. GDD's (Growing Degree Days, Base 0˚C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

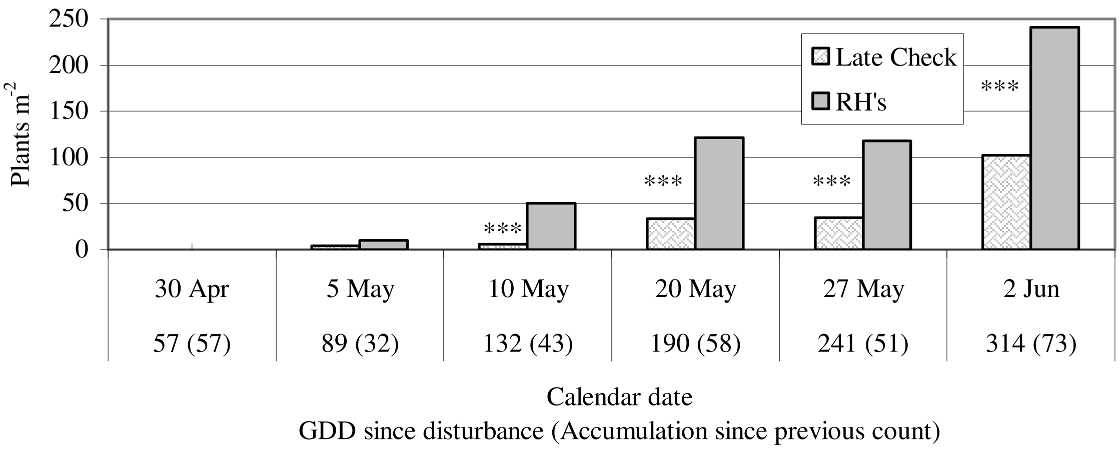

Figure 23. Pre-seed wild oat recruitment comparing the late check to the RH's at the Brandon 2004 location.

Notes: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10. All plots are Pesticide Free Production (PFP) managed. RH = Rotary Harrow
Each date represents new weeds emerged since the previous count. GDD's (Growing Degree Days, Base 0˚C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

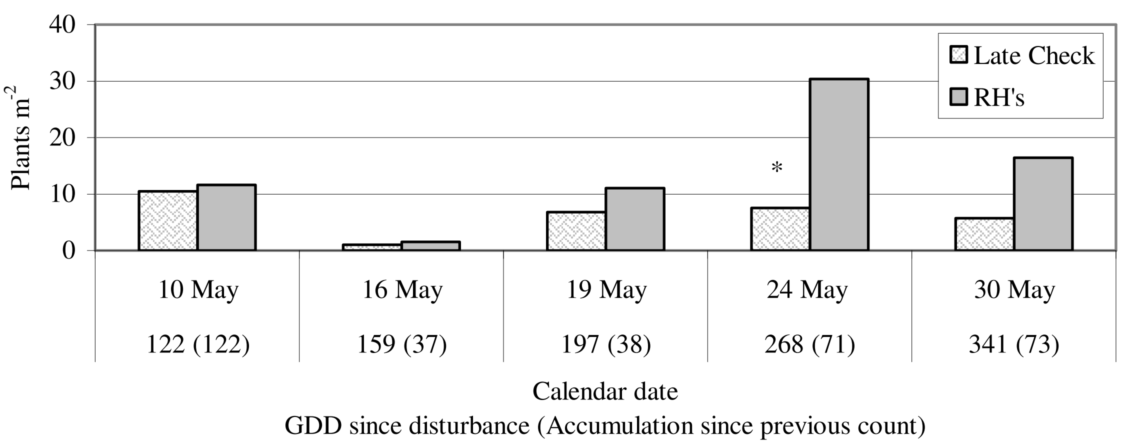

Figure 24. Pre-seed wild oat recruitment comparing the late check to the RH's at the Brandon 2005 location.

Notes: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10. All plots are Pesticide Free Production (PFP) managed. RH = Rotary Harrow
Each date represents new weeds emerged since the previous count. GDD's (Growing Degree Days, Base 0˚C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

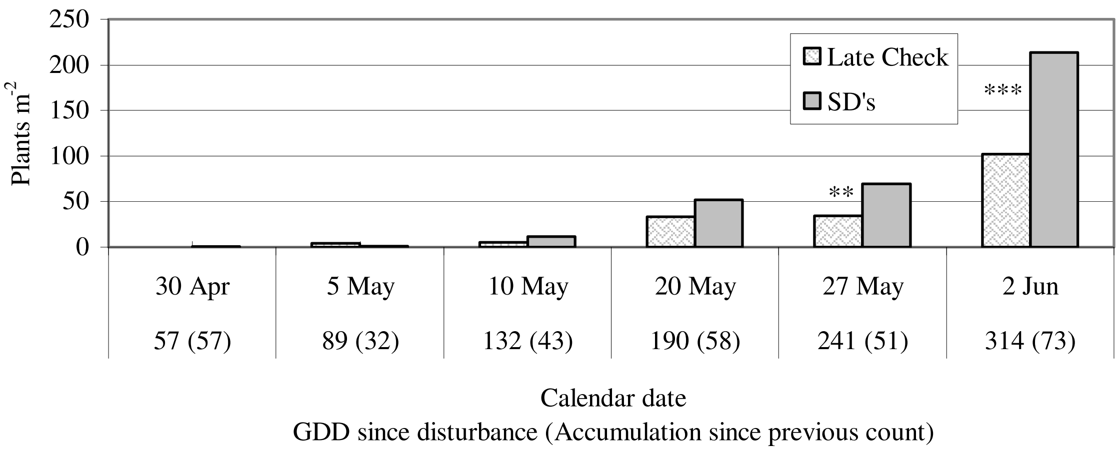

Figure 25. Pre-seed wild oat recruitment comparing the late check to the SD's at the Brandon 2004 location.

Notes: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10.
All plots are Pesticide Free Production (PFP) managed. SD = Seeder Disturbance.
Each date represents new weeds emerged since the previous count. GDD's (Growing Degree Days, Base 0°C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

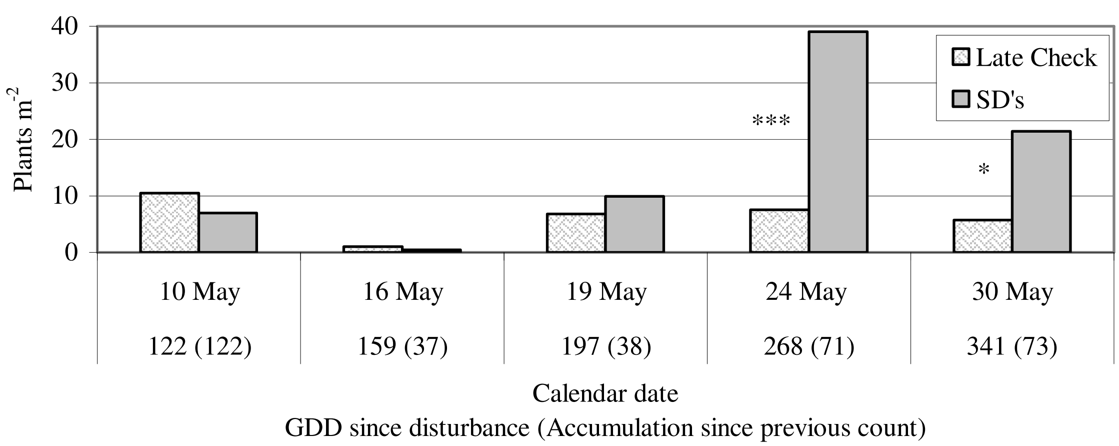

Figure 26. Pre-seed wild oat recruitment comparing the late check to the SD's at the Brandon 2005 location.

Notes: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10.
All plots are Pesticide Free Production (PFP) managed. SD = Seeder Disturbance.
Each date represents new weeds emerged since the previous count. GDD's (Growing Degree Days, Base 0°C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

Similar results were found with the seeder disturbance treatments. Wild oat recruitment was increased when seeder disturbance was used in the spring regardless of whether rotary harrowing was completed in the fall.

It was observed visually in the field that the rotary harrow mixed the soil more thoroughly and deeper in the spring compared to the fall. Because 2003 was a very dry year (Figure 4) the rotary harrow was not able penetrate the soil as deeply in the fall. The fall of 2004 was not as dry (Figure 5) as the fall of 2003 but was still not as moist as in the spring (visual observation). In the spring the ground was very moist due to the spring snow melt (Figure 10 and 11). This is likely the greatest factor in the difference between recruitment using fall or spring disturbance. It may to possible to improve the penetration of this disturbance tool or identify others which disturb the soil to a depth of less than 2 cm without knocking down stubble and create more microsites but this will require further engineering.

Seed dormancy may also play a role in the greater success of spring disturbance. In the spring, seeds would be moving towards less dormancy (Benech-Arnold et al 2000) and a short burst of light from disturbance may be just enough to break dormancy (Swanton and Booth 2004). Boyd (2003) found greater germination of wild oat seeds at higher osmotic potentials due to the presence of light. Throughout the pre-seed period moisture was unlikely to be limiting (Figure 10 and 11) and the quick exposure to light from spring tillage may have been enough to allow germination, and hence greater recruitment in the spring compared to the fall. Although the seeds would still be exposed to light in the fall they would be moving towards, or fully at, dormancy. Light is considered to be a factor that removes the ultimate constraint to dormancy (Benech-

Arnold et al 2000) meaning that the exposure to light in the fall would have little or no effect on the seeds.

4.5.1.2 Green Foxtail

Green foxtail recruitment was affected differently by stimulation techniques than wild oat recruitment. There was no recruitment at the time of early seeding for all site years which would be expected because green foxtail is a warm season grass (Boyd 2003) (Table 6). The trifluralin was able to suppress green foxtail growth at all site years for the late-seeded plots. This is contrary to wild oat results where significant suppression only occurred at one site year (Brandon 2004). One possible explanation for this is the later recruitment time for green foxtail. Since green foxtail begins recruitment later than wild oat, more time was available for the trifluralin to be carried down to the seedbank by rain. Another explanation is that green foxtail is a small seeded species which tends to be recruited from near the soil surface (Du Croix Sissons et al. 2000) where the concentration of trifluralin would be high and wild oat can be recruited from deeper in the soil profile.

There were no significant differences in green foxtail recruitment between the disturbed plots and the check plot at the late seeding date at all site years. Recruitment timing data was not analyzed because recruitment only began on the last day before seeding at the two Brandon sites. If seeding were delayed further it is possible that an effect of disturbance may have been observed.

Even though there were no differences between the disturbance treatments and the check plot, there were differences in recruitment within frequency of disturbance. This may be related to the use of contrasts in analyzing the data. The contrast compares the

Table 6. Pre-seed green foxtail density and contrast significance for all trial site years.

	Pre-Seed Green Foxtail (plants m^{-2})		
	Brandon 2004 [1]	Brandon 2005	Carman 2005
Early's vs Late's	***	***	***
Early's	0	0	0
Late's	33	7	18
Early PFP's vs Early Chem. Check	n.s.	n.s.	n.s.
Early PFP's	0	0	0
Early Chem. Check	0	0	0
Late PFP's vs Late Chem. Check	**	**	*
Late PFP's	48	8	22
Late Chem. Check	4	3	6
Early Check vs Early Fall RH	n.s.	n.s.	n.s.
Early Check	0	0	0
Early Fall RH	0	0	0
Late Check vs RH's	n.s.	n.s.	n.s.
Late Check	60	8	14
RH's	70	10	28
Late Check vs SD's	n.s.	n.s.	n.s.
Late Check	60	8	14
SD's	66	13	19
Early Nitrogen vs. No Early Nitrogen	n.s.	n.s.	n.s.
Early Nitrogen	69	11	11
No Early Nitrogen	63	15	26
Fall RH + SD vs. Spring SD only	**	n.s.	n.s.
Fall RH + Spring SD	84	14	20
Spring SD only	49	12	18
Pack vs No Pack	n.s.	n.s.	***
Pack	87	11	44
No Pack	87	10	12
Fall RH vs Fall + Spring RH	***	**	n.s.
Fall RH	37	8	26
Fall + Spring RH	87	15	45
Fall + Spring RH vs Spring RH		**	**
Fall + Spring RH	n/a	15	45
Spring RH	n/a	8	13

Notes: Significance levels refer only to pair of values directly below.
*** p<0.01, ** p<0.05, * p<0.10, n.s. not significant.
All plots are Pesticide Free Production (PFP) managed except the Chemical Check.
Early’s = Early-seeded; Late’s = Late-seeded; RH = Rotary Harrow; SD = Seeder Disturbance.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.
[1] Values did not need transformation and were analyzed without transformation.

average of all the disturbance frequencies to compare to the check. Therefore, if only one disturbance frequency shows an effect it may get diluted in the average.

In all cases, fall and spring disturbance were superior to either fall disturbance alone or spring disturbance alone (Table 6). This differs from the results of the wild oat in that wild oat only required spring tillage for recruitment regardless of whether fall tillage was performed. However, this is consistent with work by Kabanyana (2004) who found that green foxtail recruitment increased with increasing tillage intensity. Boyd (2003) determined that green foxtail recruitment was not influenced by light. Additionally, similar to wild oat, green foxtail only needed to be placed just below the surface for optimal recruitment. A study in Minnesota showed greater green foxtail populations in reduced tillage systems (Spandl et al. 1998) whereas a study in Alberta showed greater association of green foxtail with conventionally tilled systems (O'Donovan et al. 1997). The present study is different from these two trials in that it is a no-till system that is lightly disturbed. It appears then, at least in the northern part of the Great Plains, disturbance will increase the recruitment of green foxtail.

4.5.2 Post-Seed Weed Recruitment

4.5.2.1 Wild Oat

There was a varied effect of seeding date on post-seed wild oat recruitment. The Brandon 2004 location showed higher wild oat densities in the early-seeded plots, the Brandon 2005 location showed no difference between early and late seeding, and the Carman 2005 location showed greater wild oat densities in the late-seeded plots (Table 7). It is likely that the greater wild oat recruitment in the late-seeded plots at the Carman location was due to the disturbance caused by the seeder. Delayed seeding is often identified as a method to reduce wild oat pressure in organic or low input systems (Nazarko et al. 2003). Results from this study indicate that this will not necessarily work in all situations. In areas with short growing seasons the time spent in waiting for weeds to grow wastes valuable time when the crop could be growing and contributing towards yields.

Trifluralin was more effective in suppressing wild oat growth in the post-seeding period compared to the pre-seeding period (Table 7). All early-seeded plots at all site years and late-seeded plots at both Brandon locations had less wild oat growth where trifluralin was used. The recruitment patterns of the late-seeded Brandon locations (Figures 27 and 28 clearly show suppression of wild oat growth throughout the post-seed period. Of greatest interest is the Brandon 2005 location which had no effect of trifluralin in the pre-seed period. The disturbance cause by seeding (incorporation of the chemical) combined with the heavy rains in June (225 mm vs. average of 76 mm) would have helped to leach the chemical down into the seedbank. The late-seeded Carman plots showed no effect of trifluralin on wild oat control in the post-seed period (along with no effect in the pre-seed period). The chemical was applied at the same time and with the same machine as the early-seeded plots (late fall just prior to freeze up). It is unknown why there was no effect of the trifluralin on the late-seeded Carman plots.

There was no effect of rotary harrowing on the early-seeded plots at the 2005 locations. However, there was a very significant decrease of 221 plants m^{-2} in wild oat numbers in the rotary harrowed plots compared to the check plots at the Brandon 2004 location. It is unlikely that this is related to the increase of 42 plants m^{-2} in wild oat numbers prior to seeding in the rotary harrowed plots compared to the check plots because of the magnitude of the difference (i.e. growing out an additional 42 plants m^{-2} should not decrease post-seed levels by 221 plants m^{-2}). It is more likely that this is random experimental error and not a biological effect.

Post-seed wild oat densities were not influenced by disturbance for the late seeding date at either Brandon locations even though rotary harrowing and seeder disturbance increased pre-seed wild oat densities. The post-seeding recruitment patterns (Figures 29 to 32) show no effects of either type of disturbance on wild oat recruitment timing.

The Carman 2005 location was different from two Brandon locations in that wild oat recruitment was lower in the disturbance treatments. This was the expected result for all site years. By increasing pre-seed wild oat recruitment post-seed wild oat recruitment would be expected to be lowered. The Carman 2005 location had the lowest overall wild oat pressure which would indicate a lower wild oat seedbank reserve. A lower wild oat seedbank reserve would be more easily influenced by management practices because it is not as robust as a large seedbank. For example, a seedbank of 1000 seeds m^{-2} that normally produces 100 seeds m^{-2} would still have 800 seeds m^{-2} if recruitment was doubled. A seedbank with 100 seeds m^{-2} which normally produces 25 seeds m^{-2} would only have 50 seeds m^{-2} remaining if recruitment was doubled. In the case of the large seedbank doubling recruitment results in only a 20% loss whereas in the case of the small seedbank doubling recruitment results in a 50% loss. Judging from the Carman 2005 results it appears that wild oat pressure needs to be sufficiently low for any of the disturbance treatments to have an effect. More research at different wild oat pressures would help to test this hypothesis.

Table 7. Post-seed wild oat density and contrast significance for all trial site years.

	Post-Seed Wild Oats (plants m^{-2})		
	Brandon 2004 [1]	Brandon 2005	Carman 2005
Early's vs Late's	***	n.s.	***
Early's	334	55	14
Late's	135	56	28
Early PFP's vs Early Chem. Check	***	***	**
Early PFP's	453	68	17
Early Chem. Check	98	15	6
Late PFP's vs Late Chem. Check	***	***	n.s.
Late PFP's	190	70	29
Late Chem. Check	26	15	26
Early Check vs Early Fall RH	***	n.s.	n.s.
Early Check	563	69	15
Early Fall RH	342	68	18
Late Check vs RH's	n.s.	n.s.	n.s.
Late Check	179	69	37
RH's	167	84	26
Late Check vs SD's	n.s.	n.s.	***
Late Check	179	69	37
SD's	132	54	18
Early Nitrogen vs. No Early Nitrogen	n.s.	n.s.	n.s.
Early Nitrogen	131	44	18
No Early Nitrogen	133	64	19
Fall RH + SD vs. Spring SD only	n.s.	n.s.	**
Fall RH + Spring SD	125	49	13
Spring SD only	139	59	24
Pack vs No Pack	n.s.	n.s.	n.s.
Pack	166	89	24
No Pack	134	79	27
Fall RH vs Fall + Spring RH	n.s.	n.s.	n.s.
Fall RH	201	71	25
Fall + Spring RH	150	56	23
Fall + Spring RH vs Spring RH		***	n.s.
Fall + Spring RH	n/a	56	23
Spring RH	n/a	124	30

Notes: Significance levels refer only to pair of values directly below.
*** p<0.01, ** p<0.05, * p<0.10, n.s. not significant.
All plots are Pesticide Free Production (PFP) managed except the Chemical Check.
Early's = Early-seeded; Late's = Late-seeded; RH = Rotary Harrow; SD = Seeder Disturbance.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.
[1] Values did not need transformation and were analyzed without transformation.

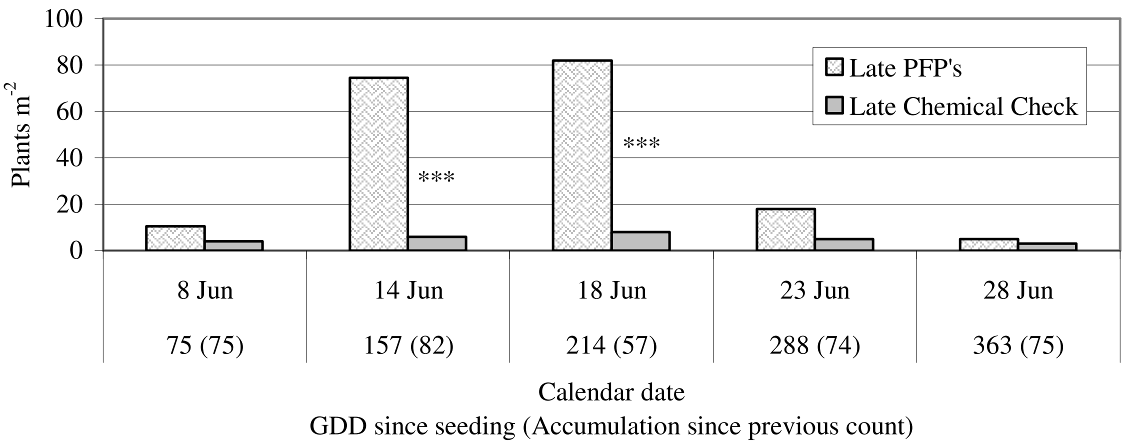

Figure 27. Post-seed wild oat recruitment comparing the late PFP's to the chemical check at the Brandon 2004 location.

Notes: Significance levels refer only to pair of values on specific date; *** $p<0.01$, ** $p<0.05$, * $p<0.10$.
All plots are Pesticide Free Production (PFP) managed.
Each date represents new weeds emerged since the previous count. GDD's (Growing Degree Days, Base 0˚C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

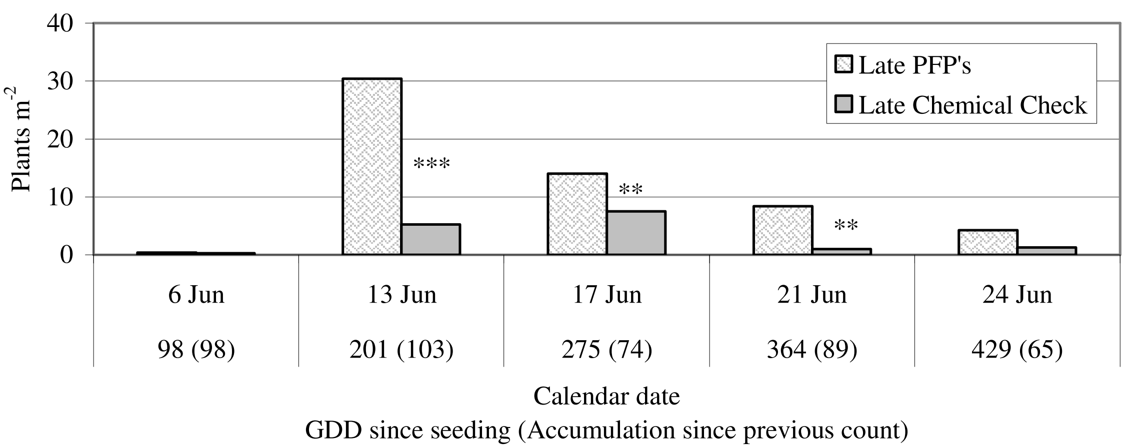

Figure 28. Post-seed wild oat recruitment comparing the late PFP's to the chemical check at the Brandon 2005 location.

Notes: Significance levels refer only to pair of values on specific date; *** $p<0.01$, ** $p<0.05$, * $p<0.10$.
All plots are Pesticide Free Production (PFP) managed.
Each date represents new weeds emerged since the previous count. GDD's (Growing Degree Days, Base 0˚C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

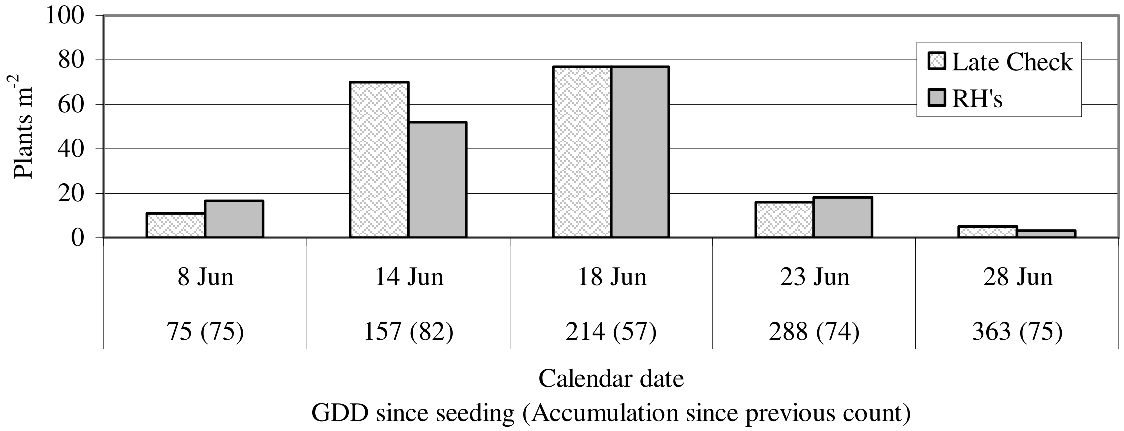

Figure 29. Post-seed wild oat recruitment comparing the late check to the RH's at the Brandon 2004 location.
Notes: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10.
All plots are Pesticide Free Production (PFP) managed. RH = Rotary Harrow
Each date represents new weeds emerged since the previous count. GDD's (Growing Degree Days, Base 0˚C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

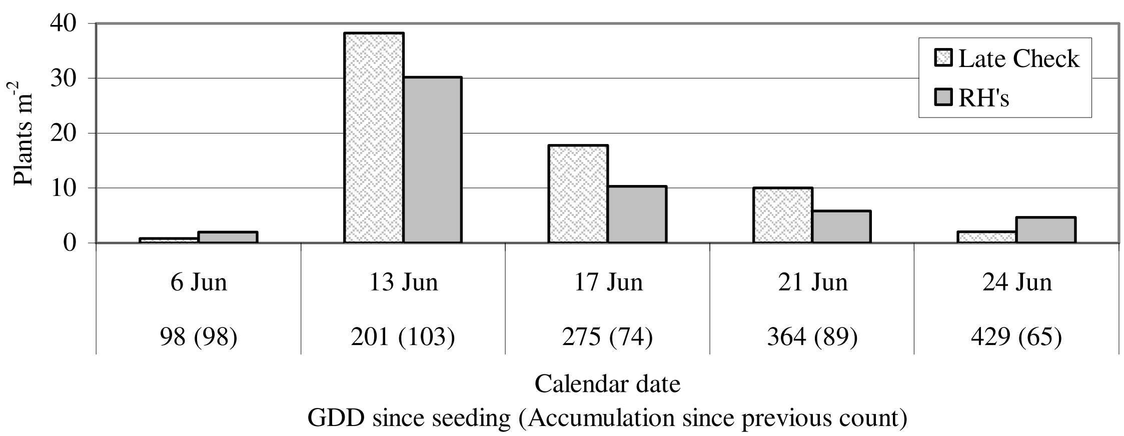

Figure 30. Post-seed wild oat recruitment comparing the late check to the RH's at the Brandon 2005 location.
Notes: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10.
All plots are Pesticide Free Production (PFP) managed. RH = Rotary Harrow
Each date represents new weeds emerged since the previous count. GDD's (Growing Degree Days, Base 0˚C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

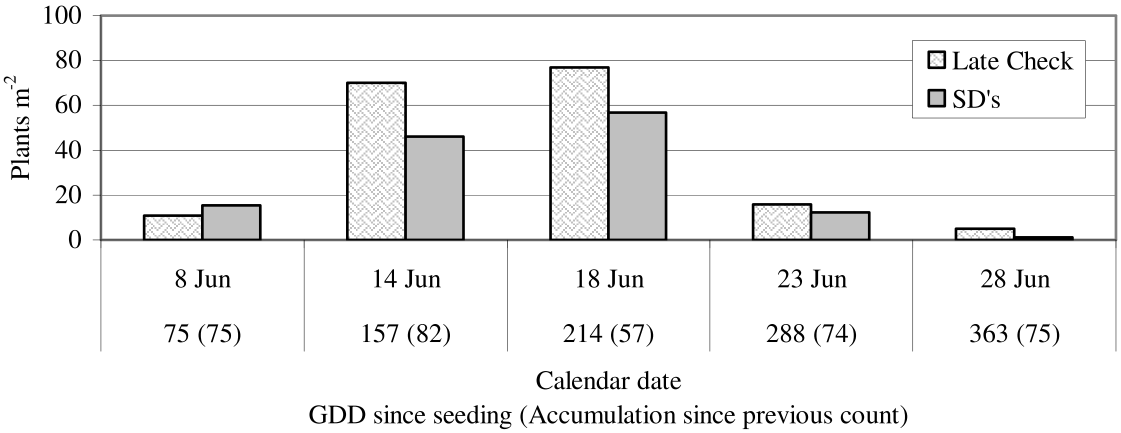

Figure 31. Post-seed wild oat recruitment comparing the late check to the SD's at the Brandon 2004 location.

Notes: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10.
All plots are Pesticide Free Production (PFP) managed. SD = Seeder Disturbance.
Each date represents new weeds emerged since the previous count. GDD's (Growing Degree Days, Base 0˚C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

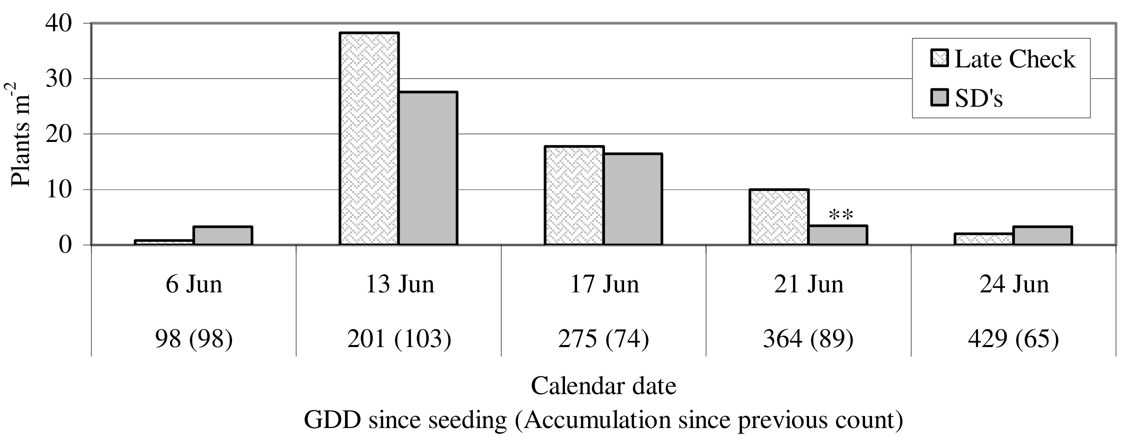

Figure 32. Post-seed wild oat recruitment comparing the late check to the SD's at the Brandon 2005 location.

Notes: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10.
All plots are Pesticide Free Production (PFP) managed. SD = Seeder Disturbance
Each date represents new weeds emerged since the previous count. GDD's (Growing Degree Days, Base 0˚C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

4.5.2.1 Green Foxtail

Post seed green foxtail recruitment was similar to wild oat recruitment (Table 8). Seeding date was not effective in lowering green foxtail numbers. The only location to have lower green foxtail numbers in the late seeding date was the Brandon 2004 location. The results here, similar to the results with the wild oat, underline that delayed seeding does not guarantee lower in-crop green foxtail populations.

Trifluralin worked well to suppress green foxtail recruitment at both Brandon locations and seeding dates. The recruitment patterns for the late-seeded Brandon plots (Figure 33 and 34) confirm that the trifluralin was working over the duration of the post-seeding period. In Carman, similar to the results of the wild oat, the trifluralin did not significantly suppress green foxtail growth in the late-seeded plots but was effective in the early-seeded plots (Table 8). It is not known why there was no effect on the late-seeded plots in Carman.

Disturbance did not affect post-seed green foxtail densities. The recruitment patterns for the late-seeded rotary harrow and seeder disturbance plots at the Brandon locations confirm no significant difference in recruitment pattern throughout the entire post-seeding period (Figures 35 to 38). Frequency and type of tillage had no effects at the Brandon locations but some effects were seen at the Carman location. Similar to the pre-seed period, more green foxtail was recruited in plots with fall and spring rotary harrowing as opposed to only fall or only spring rotary harrowing. One explanation for this observation at Carman is that the previous rotary harrowing enhanced the effect of the disturbance caused by seeding to increase green foxtail recruitment.

Table 8. Post-seed green foxtail density and contrast significance for all trial site years.

	Post-Seed Green Foxtail (plants m^{-2})		
	Brandon 2004	Brandon 2005	Carman 2005
Early's vs Late's	**	n.s.	n.s.
Early's	252	56	6
Late's	168	60	3
Early PFP's vs Early Chem. Check	***	***	**
Early PFP's	347	71	8
Early Chem. Check	63	11	1
Late PFP's vs Late Chem. Check	***	***	n.s.
Late PFP's	235	76	4
Late Chem. Check	35	13	1
Early Check vs Early Fall RH	**	n.s.	n.s.
Early Check	266	60	11
Early Fall RH	428	76	7
Late Check vs RH's	n.s.	n.s.	n.s.
Late Check	216	67	2
RH's	267	76	7
Late Check vs SD's	n.s.	n.s.	n.s.
Late Check	216	67	2
SD's	287	66	5
Early Nitrogen vs. No Early Nitrogen	n.s.	n.s.	n.s.
Early Nitrogen	266	73	5
No Early Nitrogen	309	59	5
Fall RH + SD vs. Spring SD only	**	n.s.	n.s.
Fall RH + Spring SD	331	62	4
Spring SD only	244	70	6
Pack vs No Pack	n.s.	n.s.	**
Pack	283	81	10
No Pack	264	72	4
Fall RH vs Fall + Spring RH	n.s.	n.s.	**
Fall RH	254	81	5
Fall + Spring RH	274	79	13
Fall + Spring RH vs Spring RH		n.s.	**
Fall + Spring RH	n/a	79	13
Spring RH	n/a	68	4

Notes: Significance levels refer only to pair of values directly below.
*** p<0.01, ** p<0.05, * p<0.10, n.s. not significant.
All plots are Pesticide Free Production (PFP) managed except the Chemical Check.
Early’s = Early-seeded; Late’s = Late-seeded; RH = Rotary Harrow; SD = Seeder Disturbance.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

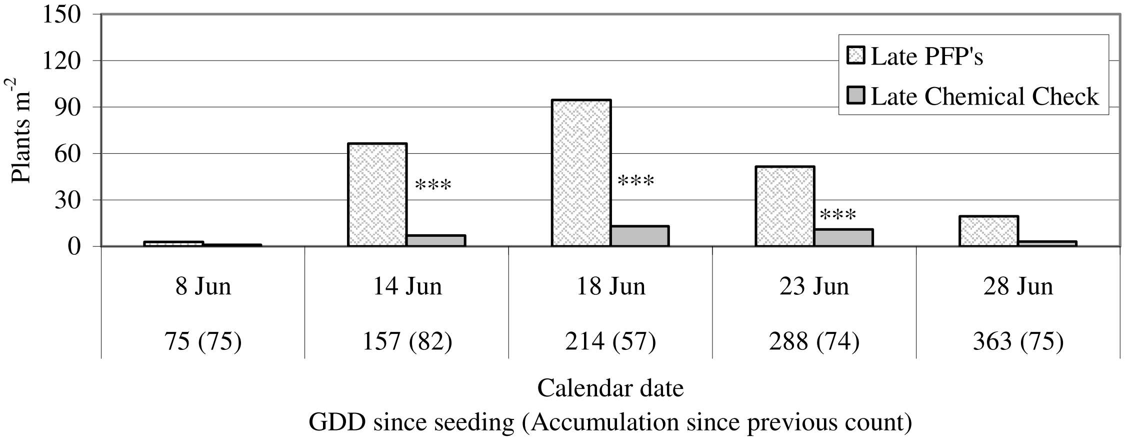

Figure 33. Post-seed green foxtail recruitment comparing the late PFP's to the chemical check at the Brandon 2004 location.

Notes: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10.
All plots are Pesticide Free Production (PFP) managed.
Each date represents new weeds emerged since the previous count. GDD's (Growing Degree Days, Base 0˚C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

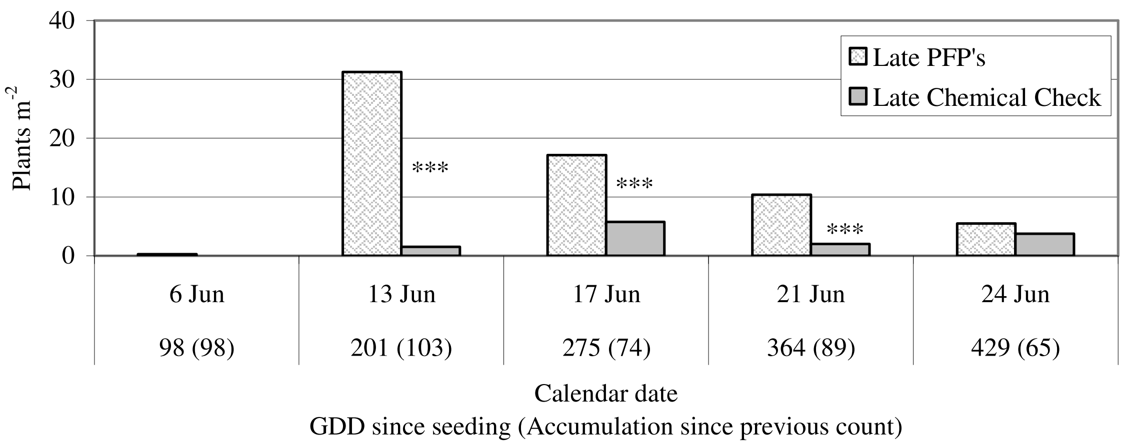

Figure 34. Post-seed green foxtail recruitment comparing the late PFP's to the chemical check at the Brandon 2005 location.

Notes: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10.
All plots are Pesticide Free Production (PFP) managed.
Each date represents new weeds emerged since the previous count. GDD's (Growing Degree Days, Base 0˚C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

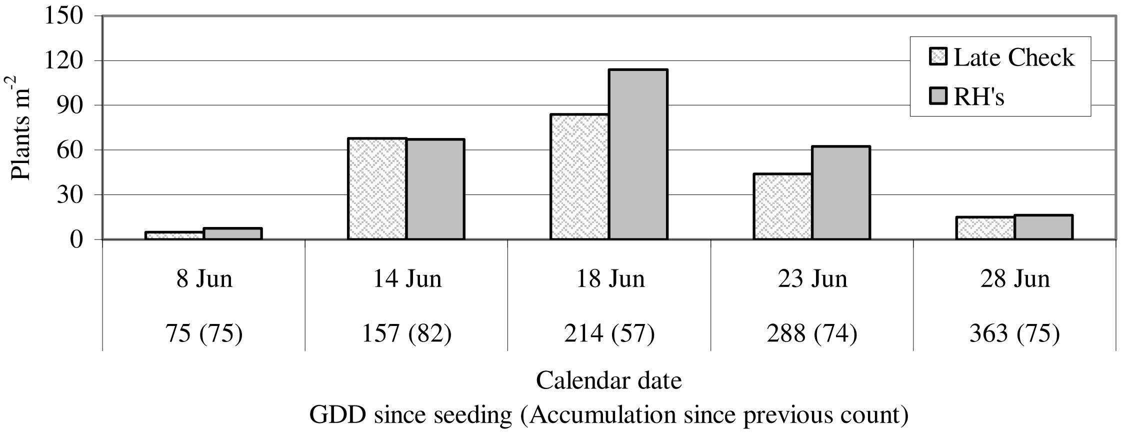

Figure 35. Post-seed green foxtail recruitment comparing the late check to the RH's at the Brandon 2004 location.

Notes: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10.
All plots are Pesticide Free Production (PFP) managed. RH = Rotary Harrow.
Each date represents new weeds emerged since the previous count. GDD's (Growing Degree Days, Base 0˚C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

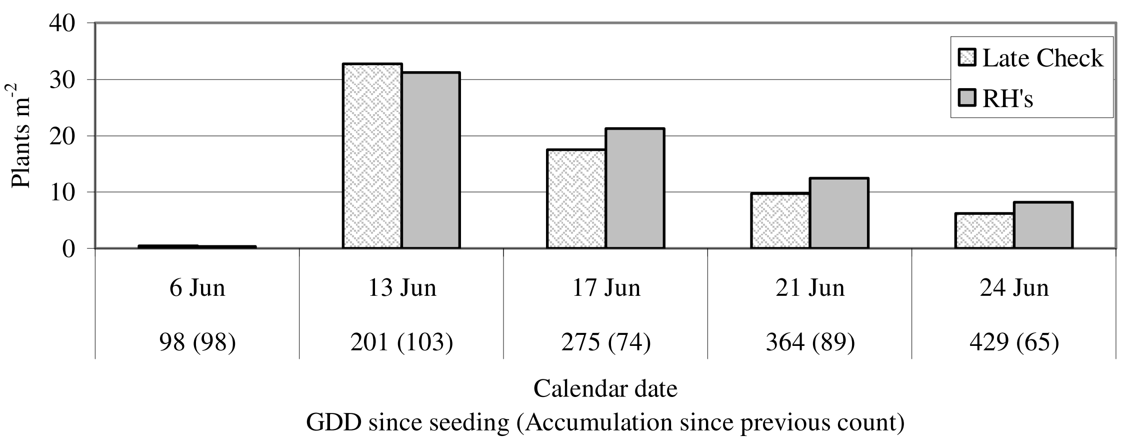

Figure 36. Post-seed green foxtail recruitment comparing the late check to the RH's at the Brandon 2005 location.

Notes: Significance levels refer only to pair of values on specific date; *** p<0.01, ** p<0.05, * p<0.10.
All plots are Pesticide Free Production (PFP) managed. RH = Rotary Harrow.
Each date represents new weeds emerged since the previous count. GDD's (Growing Degree Days, Base 0˚C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

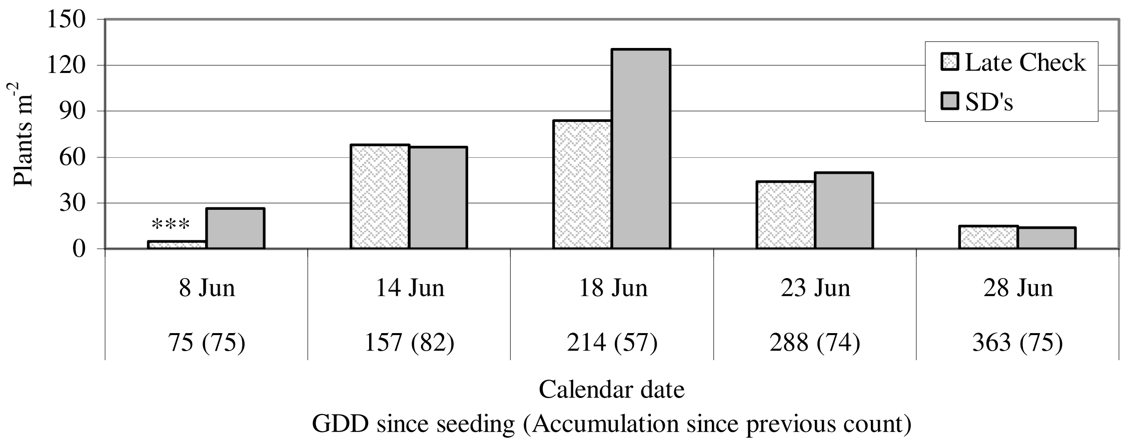

Figure 37. Post-seed green foxtail recruitment comparing the late check to the SD’s at the Brandon 2004 location.

Notes: Significance levels refer only to pair of values on specific date; *** $p<0.01$, ** $p<0.05$, * $p<0.10$.
All plots are Pesticide Free Production (PFP) managed. SD = Seeder Disturbance.
Each date represents new weeds emerged since the previous count. GDD’s (Growing Degree Days, Base 0˚C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

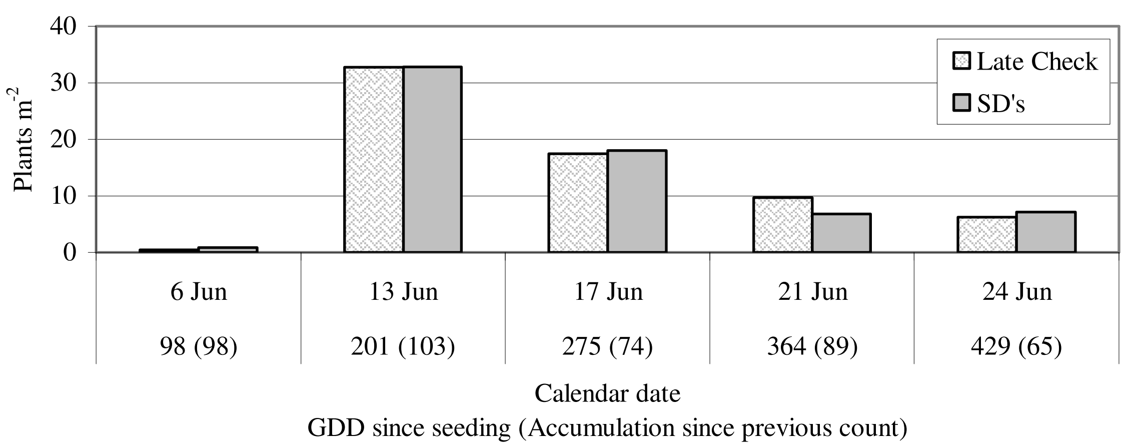

Figure 38. Post-seed green foxtail recruitment comparing the late check to the SD’s at the Brandon 2005 location.

Notes: Significance levels refer only to pair of values on specific date; *** $p<0.01$, ** $p<0.05$, * $p<0.10$.
All plots are Pesticide Free Production (PFP) managed. SD = Seeder Disturbance.
Each date represents new weeds emerged since the previous count. GDD’s (Growing Degree Days, Base 0˚C) are given as a reference for the amount of heat accumulated during each period.
All values were square-root transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

4.5.3 Weed Recruitment Summary

At all site years, pre-seed weed levels were always higher in late-seeded plots as compared to early-seeded plots. Intuitively this makes sense because the late-seeded plots are left two to three weeks longer prior to planting, allowing more time for weed recruitment. Many farmers take advantage of delayed seeding in organic or low-input systems in order to kill as many weeds as possible before seeding with the goal of reducing weed numbers after seeding (Nazarko et al. 2003). The results of the present experiment indicate that delayed seeding will not necessarily reduce post-seeding weed densities. Lower post seeding weed densities were only observed at one site year of three. Trifluralin was found to never increase weed levels and most of the time decreased weed levels in both seeding dates prior to and after seeding.

One of the goals of this project was to stimulate weed recruitment through the use of light tillage prior to planting. It was expected that light tillage in the fall prior to early-seeding would have little effect because of the short amount of time for weed recruitment to occur. In fact, in only one case did disturbance increase wild oat density at early-seeding (Brandon 2004). Since green foxtail was never present before early-seeding there was no time to influence green foxtail recruitment with disturbance.

It was expected that the greater effect from disturbance would be on late-seeded plots due to greater number of growing degree days available for weed recruitment. At all three site years, weed growth was numerically increased due to disturbance although it was not always statistically significant. After seeding it was expected that weed numbers would be lowered due to increased pre-seeding weed recruitment. Only at the Carman 2005 location did increased weed recruitment pre-seeding result in decreased weed recruitment post-seeding. At this location weed levels were the lowest of all site years leading to the idea that only in very low weed seedbank levels can light disturbance be effective in stimulating weed recruitment.

Soil banding nitrogen fertilizer early had no effect on weed recruitment pre-seeding or post-seeding. Previous work has shown that banding fertilizer nitrogen helps to reduce weed recruitment compared with broadcast nitrogen (Cochran et al.1990, Reinertsen et al. 1984, Blackshaw 2005). Had nitrogen been broadcast on the soil surface it is possible that a greater effect would have been found (Blackshaw 2005). However, surface broadcasting of nitrogen results in lower nitrogen use efficiency particularly under zero tillage where it may be immobilized by surface residues and lost by volatilization.

Half of the rotary harrowed plots were packed and half were not. Across all years, site years, and weed species, packing had no biologically significant effects on weed recruitment. This is consistent with the results of Boyd (2003) who found that heavy compaction (packing) on clay soils did not affect weed recruitment.

Fall rotary harrowing combined with seeder disturbance in the spring showed few significant effects. It appears that the disturbance from the seeder is enough to overshadow any weed stimulating effect that may have been produced by rotary harrowing. Rotary harrowing in the fall and the spring had the most consistent result in stimulating weed recruitment. For wild oat it was found that spring disturbance with or without fall disturbance was usually enough whereas green foxtail usually required both fall and spring disturbance.

4.6 Mid-season biomass

4.6.1 Crop Biomass

Crop biomass was measured to gauge the competitiveness of the crop towards the weeds in the plots. Few differences were observed in crop biomass between treatments and site years. Carman 2005 showed no significant differences between treatments and very little numerical variation (Table 9). Both Brandon locations had higher crop biomass in the late-seeded plots. This is consistent with work by Irvine et al. (2006) that showed late seeding increased flax biomass yield and fibre yield. Chemical checks had the highest biomass at Brandon 2004 only which may be attributable to the excessive weed recruitment at that location. The chemical checks at the 2005 locations showed no difference in biomass compared to the check plot. This indicates that the in-crop herbicide application had no detrimental effects on the growth of the flax plant.

4.6.2 Weed Biomass

Weed biomass was measured to gauge the overall weed pressure on the flax crop. Similar to crop biomass, there were few treatment differences in weed biomass (Table 10). At both Brandon locations the late-seeded plots had significantly lower weed biomass than the early-seeded plots. This is to be expected since the early-seeded plots have a longer period for growth by both the weeds and the crop. Weed biomass did not differ between early and late-seeded plots in Carman even though the late-seeded plots had significantly higher weed densities post-seeding. It is likely that competition between weeds in the early-seeded plots lead to lower biomass accumulation per plant. In all site years and seeding dates the in-crop weed control reduced weed biomass to near zero.

Table 9. Crop biomass and contrast significance for all trial site years.

	Crop Biomass (g m^{-2})		
	Brandon 2004	Brandon 2005	Carman 2005 [1]
Early's vs Late's	***	***	
Early's	241	288	584
Late's	348	392	716
Early PFP's vs Early Chem. Check	***	n.s.	
Early PFP's	115	276	581
Early Chem. Check	493	323	596
Late PFP's vs Late Chem. Check	***	n.s.	
Late PFP's	247	381	704
Late Chem. Check	549	424	753
Early Check vs Early Fall RH	n.s.	***	
Early Check	100	188	508
Early Fall RH	131	320	617
Late Check vs RH's	n.s.	n.s.	
Late Check	249	372	743
RH's	276	380	654
Late Check vs SD's	**	n.s.	
Late Check	249	372	743
SD's	306	371	733
Early Nitrogen vs. No Early Nitrogen	n.s.	n.s.	
Early Nitrogen	316	357	690
No Early Nitrogen	296	384	777
Fall RH + SD vs. Spring SD only	n.s.	*	
Fall RH + Spring SD	299	338	737
Spring SD only	312	403	730
Pack vs No Pack	n.s.	n.s.	
Pack	296	381	622
No Pack	287	378	686
Fall RH vs Fall + Spring RH	n.s.	n.s.	
Fall RH	245	386	684
Fall + Spring RH	291	379	635
Fall + Spring RH vs Spring RH		n.s.	
Fall + Spring RH	n/a	379	635
Spring RH	n/a	374	643

Notes: Significance levels refer only to pair of values directly below.
*** p<0.01, ** p<0.05, * p<0.10, n.s. not significant.
All plots are Pesticide Free Production (PFP) managed except the Chemical Check.
Early's = Early-seeded; Late's = Late-seeded; RH = Rotary Harrow; SD = Seeder Disturbance.
[1] Overall test not significant.

Table 10. Weed biomass and contrast significance for all trial site years.

	Weed Biomass (g m^{-2})		
	Brandon 2004	Brandon 2005	Carman 2005 [1]
Early's vs Late's	***	***	n.s.
Early's	430	121	50
Late's	276	72	41
Early PFP's vs Early Chem. Check	***	***	***
Early PFP's	637	162	67
Early Chem. Check	16	0	0
Late PFP's vs Late Chem. Check	***	***	***
Late PFP's	413	96	55
Late Chem. Check	1	0	0
Early Check vs Early Fall RH	*	n.s.	***
Early Check	693	166	105
Early Fall RH	581	159	48
Late Check vs RH's	n.s.	n.s.	n.s.
Late Check	390	138	59
RH's	411	110	63
Late Check vs SD's	n.s.	n.s.	n.s.
Late Check	390	138	59
SD's	342	114	75
Early Nitrogen vs. No Early Nitrogen	n.s.	n.s.	n.s.
Early Nitrogen	331	102	84
No Early Nitrogen	353	127	67
Fall RH + SD vs. Spring SD only	n.s.	n.s.	***
Fall RH + Spring SD	338	109	56
Spring SD only	345	120	95
Pack vs No Pack	n.s.	n.s.	n.s.
Pack	365	106	71
No Pack	430	114	56
Fall RH vs Fall + Spring RH	n.s.	*	n.s.
Fall RH	437	75	53
Fall + Spring RH	398	115	60
Fall + Spring RH vs Spring RH		n.s.	n.s.
Fall + Spring RH	n/a	115	60
Spring RH	n/a	139	77

Notes: Significance levels refer only to pair of values directly below.
*** p<0.01, ** p<0.05, * p<0.10, n.s. not significant.
All plots are Pesticide Free Production (PFP) managed except the Chemical Check.
Early's = Early-seeded; Late's = Late-seeded; RH = Rotary Harrow; SD = Seeder Disturbance.
All values were log transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.
[1] Values did not need transformation and were analyzed without transformation.

4.6.3 Crop and Weed Biomass Summary

Noticeably absent are any effects due to different treatments (disturbance, early nitrogen, frequency of disturbance) on crop or weed biomass. The overall goal of the experiment was to increase weed recruitment prior to seeding which would in turn reduce weed recruitment after seeding and lead to less competition by the flax crop from weeds. In Carman where overall weed pressure was low and disturbance resulted in less weed numbers post-seeding, crop and weed biomass were unaffected by disturbance. From this evidence it can be concluded that post-seeding weed competition as determined by crop and weed biomass was not influenced by any of the treatments applied. This is contrary to weed management practices currently employed by organic producers.

4.7 Harvest Measures

4.7.1 Seed Yield

Seed yield was not affected by any treatments other than planting date and chemical control (Table 11). At the Carman 2005 location, the overall test was not significant and values were numerically very similar. At both Brandon locations the late-seeded plots yielded higher than the early-seeded plots and the chemical checks always yielded higher than the control plot. No consistent biologically significant effects were seen for any treatment leading to the conclusion that no treatment (disturbance or early nitrogen) was able to increase yield under a PFP flax system.

The success of growing a PFP flax crop in Carman appeared only to be related to the low weed pressure found at the site. When late-seeded PFP weed biomass was regressed against yield a negative relationship was found between weed biomass values

Table 11. Seed yield and contrast significance at all trial site years.

	Yield (g m^{-2})		
	Brandon 2004 [1]	Brandon 2005	Carman 2005 [2]
Early's vs Late's	***	***	
Early's	47	78	89
Late's	65	112	91
Early PFP's vs Early Chem. Check	***	***	
Early PFP's	9	59	86
Early Chem. Check	124	135	96
Late PFP's vs Late Chem. Check	***	***	
Late PFP's	30	103	95
Late Chem. Check	134	137	77
Early Check vs Early Fall RH	**	n.s.	
Early Check	6	48	94
Early Fall RH	12	64	82
Late Check vs RH's	n.s.	n.s.	
Late Check	31	96	87
RH's	33	95	87
Late Check vs SD's	n.s.	n.s.	
Late Check	31	96	87
SD's	34	97	86
Early Nitrogen vs. No Early Nitrogen	***	n.s.	
Early Nitrogen	40	99	87
No Early Nitrogen	28	96	84
Fall RH + SD vs. Spring SD only	n.s.	*	
Fall RH + Spring SD	35	90	88
Spring SD only	33	105	83
Pack vs No Pack	n.s.	n.s.	
Pack	35	93	85
No Pack	34	97	90
Fall RH vs Fall + Spring RH	n.s.	n.s.	
Fall RH	29	107	99
Fall + Spring RH	34	96	78
Fall + Spring RH vs Spring RH		*	
Fall + Spring RH	n/a	96	78
Spring RH	n/a	81	85

Notes: Significance levels refer only to pair of values directly below.
*** p<0.01, ** p<0.05, * p<0.10, n.s. not significant.
All plots are Pesticide Free Production (PFP) managed except the Chemical Check.
Early's = Early-seeded; Late's = Late-seeded; RH = Rotary Harrow; SD = Seeder Disturbance.
[1] Values were log transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.
[2] Overall test not significant.

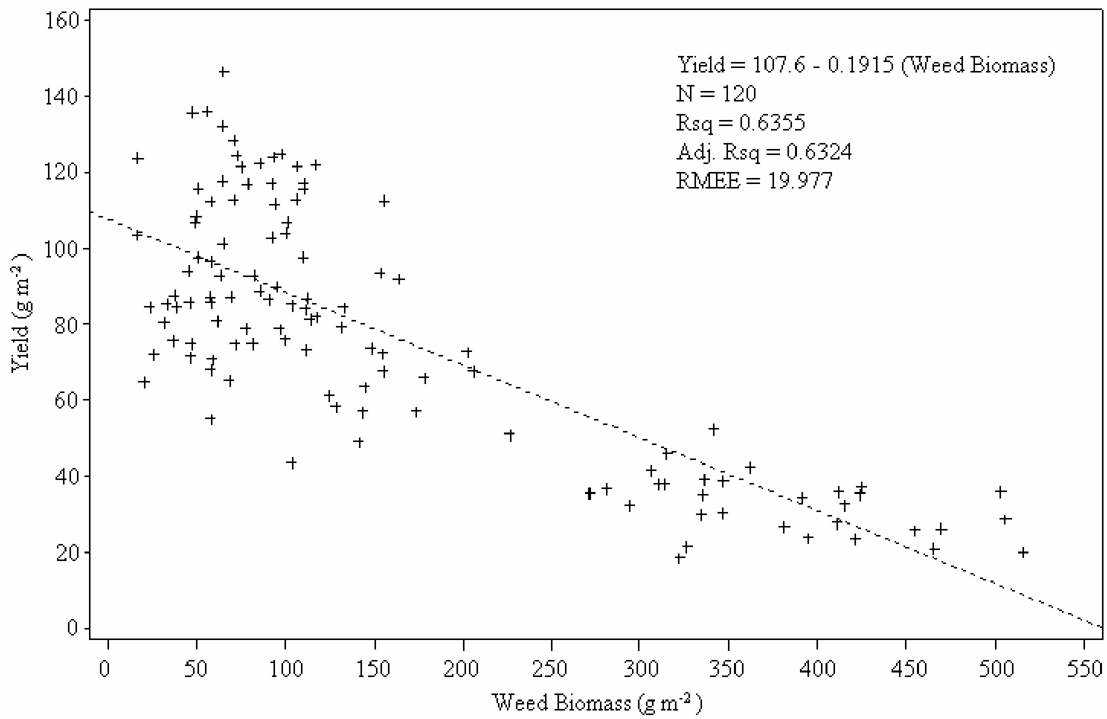

Figure 39. Regressions of weed biomass and seed yield among late-seeded PFP plots from all trial site years.

and yield values (Figure 39). This is consistent with the findings of Nazarko et al. (2004) who reported that farmers were more likely to be successful in growing a PFP crop when they chose fields that had historically low weed pressure. This indicates that developing strategies which decrease weed competition are worthwhile in the pursuit of growing PFP flax but that in-season strategies may not be worthwhile.

4.7.2 Seed Sample Dockage

As would be expected, the chemical control plots had a lower level of dockage in every year which is due to few or no weeds growing in the crop (Table 12). Late-seeded plots tended to have lower dockage which would also be due to higher crop biomass and

Table 12. Seed sample dockage and contrast significance at all trial site years.

	Dockage (%)		
	Brandon 2004 [1]	Brandon 2005	Carman 2005
Early's vs Late's	***	***	n.s.
Early's	40	38	12
Late's	31	29	11
Early PFP's vs Early Chem. Check	***	***	***
Early PFP's	55	45	15
Early Chem. Check	10	15	4
Late PFP's vs Late Chem. Check	***	***	***
Late PFP's	41	34	13
Late Chem. Check	11	15	4
Early Check vs Early Fall RH	***	n.s.	*
Early Check	69	47	19
Early Fall RH	41	44	13
Late Check vs RH's	***	n.s.	n.s.
Late Check	45	39	17
RH's	32	34	16
Late Check vs SD's	***	**	n.s.
Late Check	45	39	17
SD's	32	31	15
Early Nitrogen vs. No Early Nitrogen	n.s.	n.s.	n.s.
Early Nitrogen	30	29	15
No Early Nitrogen	33	34	15
Fall RH + SD vs. Spring SD only	n.s.	**	***
Fall RH + Spring SD	30	27	11
Spring SD only	34	35	19
Pack vs No Pack	n.s.	n.s.	n.s.
Pack	29	34	16
No Pack	33	34	15
Fall RH vs Fall + Spring RH	n.s.	n.s.	*
Fall RH	36	31	11
Fall + Spring RH	31	30	15
Fall + Spring RH vs Spring RH		***	*
Fall + Spring RH	n/a	30	15
Spring RH	n/a	41	20

Notes: Significance levels refer only to pair of values directly below.
*** p<0.01, ** p<0.05, * p<0.10, n.s. not significant.
All plots are Pesticide Free Production (PFP) managed except the Chemical Check.
Early's = Early-seeded; Late's = Late-seeded; RH = Rotary Harrow; SD = Seeder Disturbance.
All values were log transformed for data analysis to meet the assumption of homogeneity of variances.
Un-transformed values are presented.
[1] Values did not need transformation and were analyzed without transformation.

lower weed biomass in the field. At both seeding dates dockage was never higher when some type of tillage (fall and / or spring) was performed and in some cases dockage scores were significantly lower. It is unknown why this would be the case given that weed density data and weed biomass data point to no significant effect of these treatments.

Dockage levels were high in this trial although the chemical control plots were always the lowest. The Flax Council of Canada report dockage sometimes as high as 10% even in #1 grade flax (2005a). Dockage levels will be dependent on combine set up and attributes of specific manufacturers and models. Because research equipment was used and combine set up err on the side of caution, that is, harvesting the most amount of seed rather than the cleanest sample, these numbers are likely inflated compared to commercial field practices.

4.7.3 Seed Moisture

The late-seeded plots at Brandon 2004 had significantly higher seed moisture which is attributable to the short growing season and lack of heat to bring the crop to maturity (Table 13). In 2005 there were no biologically significant differences in seed moisture content between early and late-seeded plots. Late-seeded chemically treated plots tended to have higher moisture while early-seeded chemically treated plots tended to have either no difference or lower moisture. Competition hastens flax maturity (Stevenson and Wright 1996) which may have helped the late-seeded PFP flax mature sooner with the extra weed competition. The early-seeded flax had longer to dry in the field and in this case the lack of weeds in the chemical control would have allowed more air flow and subsequent drying. This effect was not observed in Brandon 2004 perhaps because less time was spent in the field after reaching maturity. No other biologically significant effects were observed among the treatments.

Table 13. Seed sample moisture and contrast significance at all trial site years.

	Moisture (%)		
	Brandon 2004	Brandon 2005 [1]	Carman 2005
Early's vs Late's	***	*	*
Early's	6.2	3.3	1.7
Late's	10.3	3.7	1.6
Early PFP's vs Early Chem. Check	n.s.	***	***
Early PFP's	6.2	3.5	1.9
Early Chem. Check	6.1	2.6	1.4
Late PFP's vs Late Chem. Check	***	***	**
Late PFP's	9.2	3.3	1.7
Late Chem. Check	12.6	4.8	1.3
Early Check vs Early Fall RH	n.s.	n.s.	n.s.
Early Check	6.7	3.6	1.9
Early Fall RH	5.8	3.4	1.9
Late Check vs RH's	n.s.	n.s.	n.s.
Late Check	9.0	3.3	1.6
RH's	9.4	3.4	1.8
Late Check vs SD's	n.s.	n.s.	n.s.
Late Check	9.0	3.3	1.6
SD's	8.8	3.5	1.7
Early Nitrogen vs. No Early Nitrogen	n.s.	n.s.	n.s.
Early Nitrogen	9.2	3.7	1.7
No Early Nitrogen	8.5	3.3	1.6
Fall RH + SD vs. Spring SD only	n.s.	n.s.	n.s.
Fall RH + Spring SD	9.1	3.6	1.6
Spring SD only	8.6	3.4	1.8
Pack vs No Pack	n.s.	n.s.	n.s.
Pack	8.8	3.3	1.8
No Pack	10.0	3.5	1.7
Fall RH vs Fall + Spring RH	n.s.	n.s.	*
Fall RH	9.5	3.3	1.7
Fall + Spring RH	9.4	3.5	1.9
Fall + Spring RH vs Spring RH		n.s.	n.s.
Fall + Spring RH	n/a	3.5	1.9
Spring RH	n/a	3.5	1.8

Notes: Significance levels refer only to pair of values directly below.
*** $p<0.01$, ** $p<0.05$, * $p<0.10$, n.s. not significant.
All plots are Pesticide Free Production (PFP) managed except the Chemical Check.
Early’s = Early-seeded; Late’s = Late-seeded; RH = Rotary Harrow; SD = Seeder Disturbance.
[1] Values were log transformed for data analysis to meet the assumption of homogeneity of variances. Un-transformed values are presented.

4.7.4 Thousand Seed Mass

Seed mass was not affected significantly by any treatments (Table 14). All values fell within the normal range of 5-7 g per 1000 seeds. The late-seeded plots had higher seed weights than the early-seeded plots at Brandon 2005 but lower than the early-seeded plots at Brandon 2004. This is likely related to the short growing season in 2004 which did not allow the plants to fully mature before harvest. Early-seeded chemical checks had higher seed mass values than late-seeded chemical checks at two locations and the opposite effect recorded at the remaining site. Late-seeded chemical checks were only higher than PFP plots in one year. Because of less competition this may have allowed the flax plants to produce larger seeds.

Table 14. Thousand seed mass and contrast significance at all trial site years.

	Thousand Seed Weight (g)		
	Brandon 2004	Brandon 2005	Carman 2005
Early's vs Late's	**	**	n.s.
Early's	5.98	5.50	5.42
Late's	5.83	5.69	5.46
Early PFP's vs Early Chem. Check	***	*	***
Early PFP's	6.10	5.44	5.34
Early Chem. Check	5.73	5.66	5.67
Late PFP's vs Late Chem. Check	n.s.	**	n.s.
Late PFP's	5.78	5.62	5.45
Late Chem. Check	5.94	5.90	5.49
Early Check vs Early Fall RH	n.s.	n.s.	n.s.
Early Check	6.02	5.49	5.44
Early Fall RH	6.19	5.42	5.29
Late Check vs RH's	n.s.	n.s.	n.s.
Late Check	5.86	5.56	5.48
RH's	5.73	5.64	5.45
Late Check vs SD's	n.s.	n.s.	n.s.
Late Check	5.86	5.56	5.48
SD's	5.79	5.72	5.49
Early Nitrogen vs. No Early Nitrogen	*	***	n.s.
Early Nitrogen	5.89	5.87	5.45
No Early Nitrogen	5.70	5.57	5.53
Fall RH + SD vs. Spring SD only	n.s.	n.s.	n.s.
Fall RH + Spring SD	5.84	5.79	5.49
Spring SD only	5.75	5.65	5.50
Pack vs No Pack	n.s.	n.s.	***
Pack	5.78	5.63	5.33
No Pack	5.70	5.65	5.56
Fall RH vs Fall + Spring RH	n.s.	n.s.	n.s.
Fall RH	5.69	5.65	5.43
Fall + Spring RH	5.74	5.67	5.32
Fall + Spring RH vs Spring RH		n.s.	***
Fall + Spring RH	n/a	5.67	5.32
Spring RH	n/a	5.61	5.59

Notes: Significance levels refer only to pair of values directly below.
*** p<0.01, ** p<0.05, * p<0.10, n.s. not significant.
All plots are Pesticide Free Production (PFP) managed except the Chemical Check.
Early's = Early-seeded; Late's = Late-seeded; RH = Rotary Harrow; SD = Seeder Disturbance.

5.0 General Discussion

The overall goal of this study was to grow flax in a no-till system with reduced herbicide inputs. Flax competes poorly with weeds and thus weed competition is generally the most limiting factor in growing a reduced input flax crop. This study focused on strategies to lower the competitive effect of weeds on the flax plant by trying to stimulate weed recruitment prior to seeding with the goal of reducing weed competition after seeding. Five specific objectives were established at the beginning of this project to measure the success or failure of this goal.

The first goal was to stimulate weed recruitment prior to seeding with the use of very shallow tillage. Because the seedbank is very close to the surface in a no-till system (Yenish et al. 1992) it is easily exploitable for weed recruitment (Mulugeta and Stoltenberg 1997). A rotary harrow (disturbance to a depth of 1-3cm) and a seeder (disturbance to a depth of 3-5cm) were used in varying combinations and frequencies to accomplish this goal. In general, weed recruitment was always stimulated and was never inhibited by the use of shallow disturbance.

At two of the three sites weed recruitment timing was tracked. At the Brandon 2004 location, the rotary harrow was found to be superior with increased recruitment beginning two weeks before seeding. At the Brandon 2005 location, no difference in the beginning of the recruitment period was found. It is unclear why this would occur without knowing where the seedbank was located in the soil profile of the two locations. More testing with similar seedbank levels and distribution would be needed to further understand this effect.

Frequency and timing of tillage affected the recruitment of wild oat and green foxtail differently. In general, one tillage pass in spring was sufficient to stimulate recruitment of wild oats whereas green foxtail had higher recruitment levels when both fall and spring tillage were performed. It is unknown why there would be a difference between the two species and what the effect would be. Both species germinate equally well as long as they are under the surface of the soil (Boyd and Van Acker 2003). Both species are also “generalist” meaning that they will germinate under a wide range of environmental conditions and will tend to be seed limited in agricultural systems (Boyd 2003). The fact that recruitment was influenced by modifying the microsite suggests that the species are somewhat microsite limited (Boyd and Van Acker 2004c). Green foxtail is a warm season grass and has a smaller seed size than wild oat. Because it is more specific in its range of recruitment temperatures the extra tillage likely increased the number of seeds located in suitable microsites to allow germination and recruitment. Wild oat is also known to be influenced by light whereas green foxtail is not (Boyd 2003). Since light only removes the ultimate constraints on germination (Benech-Arnold et al 2000) it is possible that the quick exposure to light from the spring tillage allowed greater recruitment of the wild oats.

The second study goal was to stimulate weed recruitment through the early placement of nitrogen. However, early placement of nitrogen did not have any impact on recruitment of wild oat or green foxtail. Previous work has shown that banding nitrogen into the soil rather than surface application will reduce weed recruitment (Cochran et al.1990, Reinertsen et al. 1984, Blackshaw 2005). The present study showed that timing of nitrogen placement in the spring (early applied or seed applied) did not influence weed recruitment. Blackshaw et al. (2005) found that fall applied nitrogen did not necessarily result in higher weed recruitment but never reduced weed recruitment. Had nitrogen been surface applied where the weed seedbank is at its highest concentration an effect may have been seen. Surface broadcasting of nitrogen was not included in the study because it is generally considered to be a poor management practice in Western Canada due to volatilization and immobilization (Malhi et al 2001).

The third objective was to measure the effect of shallow disturbance and early nitrogen on weed recruitment and weed competition after seeding. In general few effects could be seen from any treatment on post-seeding weed density or weed biomass (pressure). It can be concluded that wild oat, the dominant weed in the study, cannot be successfully managed using this particular combination of delayed seeding and stale seedbed techniques. Johnson (2001) came to the same conclusion regarding the effect of pre-recruitment and post-seeding tillage on wild oat management. These results underline the fact that wild oat is a very tough weed to manage and helps to explain why it is the most prevalent weed on Manitoba farms (Leeson et al. 2002). Likewise, green foxtail cannot be controlled through this combination of delayed seeding and stale seedbed techniques. Unlike wild oat, this is primarily because it does not begin recruitment until a few days before delayed seeding occurs leaving the bulk of recruitment to occur post seeding. Green foxtail is the second most prevalent weed on Manitoba farms (Leeson et al. 2002).

The results of the current study would be different in dry years. Because the tillage treatments did dry out the soil more than the un-disturbed treatments weed growth may be impeded prior to seeding if no additional precipitation was received. In the case of a dry year, the rotary harrow would be superior since it would not allow as much moisture loss as the disturbance caused by the seeder.

The overall goal of the study was to stimulate weed growth prior to seeding so that post-seeding weed levels would be lower. Although all site years showed increase in weed recruitment prior to seeding, only at the Carman location were post-seeding levels lower. However, even though post-seeding weed numbers were lower this did not alter weed competition. Mid-season weed biomass was not altered at the Carman 2005 site where weed numbers were lower after seeding. It appears, then, that weed competition is more related to the site characteristics than any management techniques that can be applied within a season. Therefore research should focus on understanding the long term techniques that lead to lower weed pressure rather than short term (seasonal) techniques as were applied in this study.

Although the treatments were not able to lower weed competition in season, they did not ever increase competition. Therefore, light tillage has potential to lower the soil seedbank levels over subsequent seasons due to greater overall weed recruitment. However, previous studies have shown that one year of high weed seed production could negate years of reduction (cited by Yenish et al. (1992). Therefore, this could be a long term solution to decreasing weed competition as long weed control is effective in every year.

The fourth objective of this study was to determine whether the weed stimulation strategies and weed recruitment were affected by seeding date. Late seeding always resulted in greater pre-seed weed densities simply because of the longer period of time for weed growth to occur. Also, because there was more time for weed growth to occur, the effect of the weed stimulation strategies was greater. For example, disturbance always increased weed recruitment in late-seeded plots whereas it only increased weed recruitment at one site year in early-seeded plots.

After seeding it was expected that there would be less growth in the late-seeded plots because of the longer period for weed recruitment prior to seeding. However, this was not always found to be the case. At location year the late-seeded plots had less post-seed weed growth, at another, there were equal amounts, and at the third location, the late-seeded plots had more weed growth than the early-seeded plots. It is unknown why there was such variation in post seed weed growth between seeding dates.

Greater weed growth did not necessarily result in greater weed competition. Plots with decreased post seed weed densities would have similar weed biomass (pressure) values mid-season. Two locations had greater weed biomass in the early-seeded plots and the third had equal growth for both seeding dates. Delayed seeding is a management practice followed by many organic farmers and farmers interested in pesticide use reduction (Nazarko et al. 2005). The results of this study indicate that this practice may not be as effective as originally thought. However, it did not ever lead to increased weed competition and in two of three cases lead to decreased weed competition.

The final objective of this study was to determine whether any of the above strategies influenced flax yield or quality. Since weed biomass, and therefore weed competition, was not reduced it was not expected that any differences would be seen. In fact, there were no biologically significant effects observed between the treatments across the site years of the study for seed yield, dockage, moisture, or thousand seed count.

Site years differed drastically in weed pressure and in mean flax seed yield. It was observed that at the site where weed biomass in PFP plots was low (Carman 2005) flax seed yields were not very different between PFP and conventionally managed systems. Conversely, at sites that had high weed biomass in PFP plots (Brandon 2004 and 2005) flax seed yields were suppressed in PFP systems as compared to conventionally managed systems. When late-seeded weed biomass and yield were regressed against each other from all PFP plots a correlation was found between low weed biomass and higher yield. This indicates that had treatments been successful in lowering weed biomass they would have been successful in increasing flax seed yield. Similar results were reported by Schoofs et al. (2005). In their study PFP flax yield was lower under a weedier forage rotation as compared to a less weedy annual rotation. Grower surveys concur that the most effective way to grow a PFP flax crop is to begin with a field that has historically low weed pressure (Nazarko et al. 2003).

Because weed pressure appears to be the most important part of growing a PFP flax crop, future research will need to focus on identifying the weed recruitment potential of a field and identifying methods to reduce this weed recruitment potential well in advance of the crop. Since flax has a low tolerance for weeds it will need a field with very little weed competition whereas a more competitive crop, such as oats, will be able to maintain grain yield at higher weed populations (Schoofs et al. 2005). By knowing the weed recruitment potential for a field a grower will be able to better decided what type of PFP crop to grow and how often. When not growing a PFP crop a grower can work at strategies to reduce the weed pressure and recruitment potential for coming PFP crops.

Studies have shown that the soil seedbank is a poor predictor of weed recruitment in the subsequent season (Swanton and Booth 2004). This is not surprising because the environment drives weed recruitment and environmental conditions cannot be predicted from one season to the next. Environmental conditions in the previous year may also play a role in determining the recruitment potential of a seedbank in the present season. For example, seeds produced in a hot, dry year may behave differently in the same conditions as seeds produced in a cool, wet year (Irvine 2006). New research in this area is needed to understand the interaction between dormancy as a result of conditions during seed production and the subsequent macro and micro environmental conditions on the potential of weeds to germinate.

Further work should concentrate on better understanding the specific microsite requirements of weed species. Soil temperature and soil moisture are the major drivers for weed recruitment models but in this study were found not to influence weed recruitment differences between tillage treatments. This could be the source of many of the errors associated with predictive models. Measurement of soil moisture at very shallow depths is technically difficult and soil moisture changes rapidly even over short time periods making model development challenging. Boyd (2003) suggests doing experiments on different weed species or on groups of weed species to determine what specific requirements they have. By better understanding microsite requirements, techniques can be developed for encouraging weed recruitment when it is desired or suppressing it when weed recruitment is not desired.

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