UNIVERSITY OF ALBERTA

The Effect Of Three Tillage Systems On The Growth Of Cultivars Of Canola (*Brassica napus*), Barley (*Hordeum vulgare*), And Field Pea (*Pisum sativum, var. Arvense*).

BY

Thomas L. Jensen ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Doctorate Of Philosophy.

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled The Effect of Three Tillage Systems on the Growth Cultivars of Canola (*Brassica napus*), Barley (*Hordeum vulgare*), and Field Pea (*Pisum sativum,* var. *arvense*), submitted by Thomas L. Jensen in partial fulfillment of the requirements for the degree of Doctorate of Philosophy in Agronomy.

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For my Family:

Sharon, Russel, Annae, and Jana

Abstract

Two sets of experiments were conducted to determine the effects of tillage systems (conventional tillage, minimum tillage and direct seeding or no tillage) on crop growth. The objective of the first set of experiments was to test the hypothesis that there is an interaction between tillage systems and cultivars of canola (*Brassica napus*), barley (*Hordeum Vulgare*), and field pea (*Pisum sativum*, var. *arvense*) grown under central Alberta conditions. There were some observable interactions of canola and barley cultivars with tillage systems, i.e. one out of four site-years for canola, and two out of five site-years for barley. No interactions were observed in the three site-years of experiments using field peas. It was concluded that existing practices for breeding field crops and selecting improved cultivars need not be changed significantly in response to the increased use of direct seeding or minimum tillage compared to the use of conventional tillage in the Parkland region of the Canadian Prairies.

The objective of the second set of experiments was to test the hypothesis that there are differential allelopathic effects from cultivar residues within one crop species on the subsequent growth of another crop species, as affected by tillage system. The effect of different canola cultivar residues on the subsequent growth of cultivars of barley, and different barley cultivar residues on the subsequent growth of cultivars of canola were both examined. Differences among canola and barley cultivar residues and as subsequent crops within both species were observed in laboratory, greenhouse, and field experiments. Allelopathic effects were less for surface applied residues in the greenhouse compared to residues mixed into soil, two treatments used to simulate direct seeding and conventional tillage respectively. It was also observed that crop residues applied to topsoil resulted in less allelopathic effects than when applied to a loamy sand growth medium . In the field differential allelopathic effects of residues were little affected by tillage system.

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CHAPTER 1. INTRODUCTION

1.1 Background

For millennia, tillage or soil mixing by cultivation has been a common practice to prepare land for growing crops. Tillage is done for two main reasons: to control weeds and to prepare a suitable seedbed for crops. Tillage systems have changed since the grasslands, parklands and boreal forests in the Canadian Prairies were plowed, and, or cleared for field cropping. These changes are the result of developments in equipment, herbicides, and techniques to control soil erosion and conserve moisture.

Tillage systems can be classified by the amount of crop residues retained on the soil surface. Conventional tillage (CT) is a term used to describe a cultivation system where the soil within the plow layer (0 to 20 cm) is inverted by plowing, disking or multiple chisel plow operations, followed by harrowing. These operations are done to control weeds, work in previous crop residues, incorporate herbicides, and prepare a seedbed. Under CT, little crop residue is retained on the soil surface. Conservation tillage is a general term used to describe a wide range of cultivation systems that use less soil disturbance than conventional tillage. To be commonly accepted as conservation tillage a minimum 30% cover of the soil surface by crop residue is maintained between the harvesting of one crop and the planting and emergence of the next crop (Crosson 1982). Two types of conservation tillage in use are minimum tillage (MT), and no-tillage or direct seeding (DS).

MT is a tillage system used that retains as much residue as possible while still using only some (one to three) pre-seeding cultivations. These cultivations are commonly done with low-disturbance chisel plows equipped with sweeps. As the name implies there is a minimum amount of soil disturbance performed, but weeds are still controlled, herbicides might be incorporated and a seedbed prepared.

DS is a system where weed growth is controlled using pre-seeding non-selective herbicides, and post emergent herbicides, the only soil disturbance occurring is a result of the soil engaging properties of the seeding implement. If the soil engaging opener causes half to total soil surface disturbance, such as an air seeder equipped with wide sweeps, it is called high-disturbance DS. If the disturbance affects half or less, down to as little as seven percent of the soil surface it is called low-disturbance DS. For the purpose of discussion in this report CT and MT are as described above, and DS is low-disturbance.

Although CT, MT, and DS are all in use today in the Western Canadian Prairies, the proportion of farm managers using each of the three tillage systems has changed over time and very dramatically over the past decade. For example, from the beginning of agriculture in the late 1800s on the Prairies, through the early 1900s nearly all farmers used CT. It was not until the late 1930s that a reduction in tillage was introduced. This introduction in reduced tillage was called "stubble mulch farming" and was characterized by a technique of soil cultivation that left the majority of crop residue prior to the cultivation on the soil surface. By the late 1960s MT began to be used, and DS or no-tillage (NT) began to be evaluated when non-selective herbicides such as Paraquat and Glyphosphate (ROUNDUP) became available. Much of the early research into NT and DS, in Western Canada was conducted at Agriculture Canada Research Stations (Lindwall 1985). Similar research has been conducted at other research stations and at university research farms across Western Canada (Stobbe 1979). In the late 1970s a small number of farm managers began to use DS. Their numbers expanded slowly and a few farmer conservation groups were organized during this period such as the Manitoba-North Dakota Zero-till Association, the Alberta Conservation Tillage Society (ACTS), and later in the 1980s the Saskatchewan Soil Conservation Association, and the Peace River Conservation Tillage Association. One of the first extensive surveys of the use of conservation tillage by farmers in Western Canada was a joint project of ACTS and Alberta Agriculture (Jensen 1988). It was determined in this survey that as of March of 1987 that less than one percent of Alberta grain growers used DS. In a follow-up survey in 1992, contracted by ACTS and Alberta Agriculture the percentage of grain growers using DS had increased to three percent (Haigh and Haigh 1992). In 1994 Monsanto Canada conducted a survey and the results showed that approximately 13% of farmers in Western Canada were using DS (Personal communication with Monsanto Canada Ltd. 1994). All indications are that the adoption of DS technology by farm managers in Western Canada is continuing to increase. It has been noted that farmers adopt new technology only after careful studies of alternatives and thoughtful consideration of all the implications of change (Francis 1991). It appears as though a significant and growing group of farmers in Western Canada appear to have considered the implications of change, and determined that MT and DS are technologies that can be used effectively. Early adopters of conservation tillage technology were motivated by strong soil conservation and environmental ethics. However many growers are now motivated by economics. The development of seeding equipment capable of clearing crop residues, the invention and availability of efficient and economical straw and chaff management equipment, the price of ROUNDUP decreasing relative to the cost of tillage operations, and savings in time when MT or DS is used compared to CT along with a shortage of farm labor, has resulted in conservation tillage practices being more profitable than conventional tillage.

Because DS and MT use is increasing, this could affect the way plant breeders need to select new crop cultivars for use in Western Canada. They could breed, and select for traits for specific adaptation to MT or DS. Kauft (1994) noted that a grower is primarily interested in new cultivars that provide improved economic return. The most common method for achieving this goal is to develop new cultivars capable of producing higher yields. Higher yields with no increase in inputs result in an increased net income for a grower.

Another way to achieve an improved net income is to develop cultivars that can be grown with fewer inputs. MT or DS are cropping methods that use less fuel energy, and tillage equipment inputs than CT. If DS and MT result in micro-climates sufficiently different from CT, there is the potential that crop cultivars that are best adapted to CT may not be the best adapted for use in MT, or DS.

A significant portion of crop improvement efforts in developed countries takes place under conventional, high input production conditions. Resulting cultivars, whether hybrids, pure lines, or synthetics, are thus selected for, and adapted to these conditions. This inadvertent or cryptic breeding is an underlying constraint on any attempt to change agronomic practices, whether that be intercropping, no-till, cover cropping, ridge-till, reduced herbicides and insecticides, or green manure applications (Smith and Zobel 1991). Yield testing should be conducted under conditions as similar as possible to commercial production practices.

An accepted protocol to prepare land where plant breeding work is conducted is to summer fallow the field the previous year and to plant into a relatively residue free seedbed. Thus most of the existing cultivars of crop species grown have been selected and evaluated using CT, and the majority of parental stock comes from a long history of CT culture (Elmore 1987). However, even among existing cultivars that have been bred and selected using CT there may be sufficient genotypic diversity in relation to growth and yield response under different tillage systems that additional selection or screening using MT, and DS may be warranted.

To justify the extra expense to screen potentially beneficial genotypes for their adaptation to MT, or DS, there would need to be a consistent interaction between tillage systems and the specific crop genotypes. As well, phenotypic traits resulting from genotypic differences that can be identified and selected for would need to be manipulated by plant breeders if selection for specific adaptation to MT or DS is possible.

From all indications from the grower surveys noted above, the trend towards drastically reduced tillage will continue. To the extent that these reduced tillage systems are similar to CT the same constraints will limit productivity in both systems, and the breeding and testing strategies will not differ (Francis 1991). It is only if differences in micro-climate are large enough among CT, MT, and or DS, that the genetic traits that exhibit phenotypic differences in emergence, growth, and yield, would of necessity need to be selected. Environmental differences that induce genotype by environment (GxE) response are much more prevalent in the soil than in the air. Genotype by environment response is differential genotypic expression across environments (Romagosa and Fox 1993).Conservation tillage procedures will most likely induce GxE responses (Smith and Zobel 1991).

One known difference between a CT seedbed and a DS seedbed is a cooler soil temperature in the seedbed under DS compared to CT (Green 1984). Residues on the soil surface insulate the cooler soil surface from the warmer air temperatures in the spring and reflect sunlight decreasing the amount of radiant energy absorbed by the soil. Both of these effects of surface residues result in cooler seedbed temperatures.

Variation exists among cultivars of some crop species when they are subjected to differences in soil temperature when germinating, and emerging from a soil. Baker (1990) reported the effect of different seeding dates for two years, 1986, and 1987, on the growth of four semi-dwarf and five normal height spring wheat cultivars. By planting at different seeding dates the spring wheat cultivars were subjected to different soil temperatures, the earlier seeding date characterized by cooler soil temperatures. Least-squares analysis of cultivar means were used to demonstrate interactions between genotypes and years and seeding dates. Significant crossover interactions for days to maturity suggested that genotypes changed in rank from year to year or from seeding date to seeding date within years. In this study as in any study that is conducted in the field it is difficult to control many of the environmental factors that can affect seed germination, seedling emergence and crop growth. By having seeding date as an experimental factor there are other factors that could have also affected wheat growth. For example the length of photo-period would increase from the early May to the mid-May and to the latter-May seeding dates. There could also be differences in seedbed moisture contents, less moisture if little precipitation was received during the month of May, or perhaps more moisture if heavy precipitation was received..

Variability in germination under cooler soil temperatures has been demonstrated for six-row barley cultivars grown in the Western Canada. Dunn and Briggs (1991) assayed fifteen cultivars for germination rate and seedling growth rates at a range of temperatures from 2.5 to 20 degrees C in growth cabinet, laboratory tests, and field trials. They reported significant differences among cultivars. Four of these cultivars were also used in the experiments of this study. Three of the cultivars (Heartland, Noble and Leduc) were observed to have intermediate tolerance to cool temperatures, and the other (Bonanza) was observed to have good tolerance. Briggs (1995) subsequently reported that rapid and vigorous germination in soils at low temperature (5 to 10 degrees C) is desirable in crops to allow for early seeding for season extension, and for adaptation to minimum till management systems where residue cover may slow soil warming. Actual soil temperatures at seeding depth in the spring are lower than the optimum germination temperatures (20 to 25 degrees C) under Western Canadian conditions for most cereal crops, whether CT, MT, or DS is used. When the tillage systems are compared DS usually has slightly lower soil temperatures than MT or CT.

Not all the other differences between DS or MT systems compared to a CT system besides cooler soil temperatures are well understood. Some researchers have reported increased concentrations of adverse allelopathic compounds in the seedbed originating from residues left on the soil surface (Blum et al. 1992). Others have observed increased potential for foliar plant diseases from fungal spores spreading from the residues that are left on the soil surface and not incorporated by soil cultivation (Windels and Warnes 1996). Less disturbance of the surface layer of soil can decrease evaporative losses from the soil. The presence of surface residues in itself decreases the susceptibility of the soil to erosion by wind or water. The presence of standing stubble in DS fields slows down the movement of air at the soil surface, both reducing moisture losses as well as heat exchange to or from the soil with the air.

The type of crop rotation can affect whether there are moderate or small differences on crop growth in relation to tillage systems. For example, continuous cropping tends to increase the differences among tillage systems compared to a crop-fallow rotation. A field that has been fallowed using only herbicides will have much less intact and undecomposed residues in relation to a field that is continuously cropped and is seeded using DS compared to CT. In a crop-fallow rotation, the residues left on the soil surface in a herbicide only fallow system are subject to weathering and decomposition for a period of 20 months from harvest of one spring seeded crop until the seeding of another spring seeded crop. Under continuous cropping, the time interval between harvest and seeding is only eight months.

There are some effects of different tillage systems on plant nutrient cycling in the soil. This is because the residues are left on the soil surface when DS is used and not mixed into the soil when tillage is used. Those nutrients that tend to be slowly mobile in the soil such as phosphorous and potassium accumulate towards the soil surface. The availability of these nutrients may be somewhat affected.

The longer a field is cropped using DS compared to MT or CT, the greater the difference in the build up of a surface thatch of recently deposited plant residues on the surface and progressively decomposed plant residues down towards the soil surface. The residue thatch does not continue to get deeper and deeper because mechanisms come into effect that decompose and incorporate the material into the soil. This is largely accomplished by the action of soil microbes including fungi and bacteria, and soil animals such as insects and earthworms. When CT or MT is used this residue thatch does not build up. Not a lot is known about the long-term effects of this residue build up on crop growth under DS compared to MT or CT.

Changing from use of CT to progressively less tillage under MT and even less tillage under DS will affect the types of weeds and the relative numbers of weeds that are part of the weed spectrum present in a field. As tillage is reduced the dependence on herbicides to control weeds increases. A field where DS is used will be dominated by weeds that thrive where there is less soil disturbance, and that are also resistant to the herbicides used. For example one weed that seems to increase in DS fields is foxtail barley (*Hordeum jubatum*). It does well where there is no cultivation of the soil and is also somewhat tolerant of the use of ROUNDUP. However, it is easily controlled with cultivations. This type of weed problem may be best overcome in a practical way by using a tillage system rotation on a field. In this way the occasional use of tillage every few years will keep such weeds under control.

It is important to note that not all DS systems are identical in the amount of soil disturbance. The least amount of soil disturbance or mixing is done with a seeder with a very narrow disc-type soil engaging opener is used. If a narrow hoe-type opener is used there is usually more mixing of the soil, and if a wide hoe-type opener or a sweep opener is used there can be considerable soil mixing. The more soil mixing the more similar the tillage system will be to MT, or even CT.

The adverse allelopathic effect due to phytotoxic compounds being leached from the previous crop residues or from the production of toxic secondary metabolites from the decomposition of the residues through microbial decomposition has been researched (Kitou and Yoshida 1993). These allelopathic effects can affect crop growth and yield in two ways in relation to variation within crop genotypes. One is that genotypes within a crop species may vary in their ability to tolerate the allelopathic chemicals present in the residues (Ray and Hastings 1992). The other is variation as far as the types of, or concentration of the allelopathic chemicals within the residues of crop genotypes previously grown and left on the soil surface under MT or DS culture (Purvis and Jones 1990). Certain crop residues have been shown to contain adverse allelopathic compounds, and it is sometimes thought that the most reasonable way to minimize or avoid the effects is to bury the residues using intense tillage operations, such as plowing (Harper 1987). There seems to be a preconceived conclusion that if adverse allelochemicals are present in crop residues their effect will be more pronounced under MT or DS culture compared to CT. There is evidence for less or more potential adverse allelopathicity from DS compared to CT, and the specific effect depends on the source species, and the target species (Gubbels and Kenaschuk 1989, White et al. 1989).

The investigation of the effects on plant disease incidence of CT compared to MT, and or DS has shown contrasting results. In some studies certain fungal diseases have been observed to increase in incidence under DS compared to CT (Cook et al. 1980, and Ditsch and Grove 1991), while in the same or other studies the incidence of other fungal diseases has been shown to be similar or even to decrease (Ditsch and Grove 1991). The importance of genetic diversity and traits for specific adaptation to the effects of cooler seedbed temperatures, the adverse allelopathic compounds, and the potential increase in fungal spores as a result of the presence of previous crop residues under conservation tillage, should not be overlooked in the development of cultivars.

1.2 Study Objectives

The first objective of this study was to determine whether or not interactions exist between cultivars within the crop species of canola (*Brassica napus*), barley (*Hordeum vulgare*)and field pea (*Pisum sativum*, var. *arvense*), and tillage systems. Experiments described in Chapter Two were designed to test the hypothesis that CT, MT, and DS affect the yield of selected cultivars within a crop species differently and that interactions between tillage systems and crop cultivars exist. If observable interactions between tillage system and crop cultivars occurred, this could impact the methods used to select crop cultivars within breeding programs, and how regional evaluation is conducted. The comparison within each experiment was made between tillage systems and crop cultivars within a single species, not among different crop species.

The second objective of this study was to determine whether or not an adverse allelopathic crop growth response from selected cultivars of one crop species in the presence of residues from various cultivars of another crop species are affected differently by the three tillage systems CT, MT and DS. Experiments described in Chapter Three were designed to test the hypothesis that there are different levels of allelopathic effects caused by source residues from different cultivars of canola on different target cultivars of barley, from different cultivars of barley on different target cultivars of canola, and that the target cultivars differ in their ability to tolerate the allelopathic effects. Also that there is an increased amount of adverse allelopathic effects from the tillage systems of MT and DS compared to CT.

Therefore, the first set of experiments examined the effects of the three different tillage systems on crop cultivar growth, while the second set of experiments examined whether or not there are allelopathic effects of specific crop cultivar residues on subsequent crop growth and whether or not this is affected differently by the three different tillage systems.

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CHAPTER 2. THE EFFECT OF CONVENTIONAL TILLAGE, MINIMUM TILLAGE, AND DIRECT SEEDING, OR NO-TILLAGE, ON THE GROWTH AND YIELD OF SELECTED CULTIVARS OF CANOLA (*BRASSICA NAPUS*), BARLEY (*HORDEUM VULGARE*), AND FIELD PEA (*PISUM SATIVUM*, VAR. *ARVENSE*) IN CENTRAL ALBERTA.

2.1 Introduction

In most of the early studies comparing conventional tillage (CT), minimum tillage (MT), and direct seeding (DS), the comparisons were made using only one cultivar of a specific crop species. Emphasis was on determining whether or not the conservation tillage systems, MT or DS, resulted in similar or different yields compared to CT (Kuipers 1970, Deibert et al. 1978, Stobbe 1979, Cannell 1981, Papendick 1984). Tillage system by crop species interactions have been observed from research in Saskatchewan and Manitoba. Borstlap and Entz (1993) observed that field pea yields increased more, relative to wheat (*Triticum aestivum*) yields or canola yields when grown under DS compared to CT. Johnston et al (1995) also observed that certain crop species yielded comparatively better under DS compared to other crop species. A reasonable amount of research has been done to investigate the effects of various tillage systems on the growth of a single crop cultivar within one species and the effects of various tillage systems on the growth of cultivars from different crop species. As more knowledge was gathered as to the effect of reducing tillage on crop growth there have been studies conducted to determine the growth response and yield of different cultivars within one crop species under contrasting tillage systems (Allan 1982, Allan and Peterson 1986, Colvin and Brecke 1988, Elmore 1990, Cox 1991, Ditsch and Grove 1991, Lueschen et al. 1991, Bauer and Black 1992, Grichar and Smith 1992, Hwu and Allan 1992, Graves et al. 1993, O'Conner and Gusta 1993, and Moes and Domitruk 1995). The rationale behind this research was to determine whether or not cultivars perform similarly in relation to one another when grown using different tillage systems.

The goal of many breeding program is often to select for high average yield and a low genotype by environment interaction (Bramel-Cox et al. 1991). This has resulted in the development of genotypes adapted to high yielding environments in which wide adaptation is possible through the use of irrigation and fertilizer, but the approach has been unsuccessful in increasing yield under severe stress and may have even hampered progress in selecting for cultivars capable of improved yields under poorer growth conditions. The cooler soil temperature conditions for germination and emergence under DS and or MT, compared to CT could be considered less than optimal and more stressful for crop growth. Bramel-Cox et al. (1991) emphasized that breeders concerned with germplasm development for alternative systems would be well advised to remain aware of agronomic research developments in the area of low-input, sustainable agriculture. Increased productivity potential in genotypes used in lower input cropping systems will be critical to the development of an agricultural system that requires fewer external inputs, is more self-sustaining, less harmful to the environment, and yet productive to meet the increasing demand for food. Compared to CT, MT and DS are lower input systems, as far as tillage inputs.

The need to enhance productivity of cultivars under different stresses imposed by changes in cropping practices has been expressed by Sleeper et al. (1991). It was their opinion that plant breeding can serve an important role in the success of sustainable farming because production requires seed or other propagules, regardless of management system, and that by introducing superior genetic materials at competitive prices, productivity is enhanced cost effectively. They further noted that there are cropping patterns emerging that change varietal requirements to the extent that we need to reassess breeding objectives and methods and to anticipate future needs.

Coffman and Smith (1991) advocate investment into breeding programs for low-input, sustainable agricultural systems by producing cultivars with resistance or tolerance to biological, physical, and chemical stresses characteristic of these systems. Characteristics of micro-environments for DS compared to CT need not always be considered more stressful. For example, DS of winter wheat in Western Canada has been considered a better management practice than CT (Fowler 1983). DS along with development of more winter hardy winter wheat cultivars has allowed the expansion of winter wheat into areas previously cropped to only spring seeded crops. The maintenance of stubble residue when DS is used and the resultant trapping of snow insulates the root zone of the winter wheat relative to CT, and improves winter survival (Wilhelm et al. 1989). It may be somewhat disadvantageous in the early spring as lower soil temperatures then, slow down growth and development of the winter wheat plants. However, the somewhat cooler soil temperatures may be advantageous in the summer, to reduce evaporation of soil moisture. In this instance, instead of breeding and selection with the goal of adaptation to increased stress, the goal could be to select for the ability to take advantage of the different environment under DS compared to CT.

Smith and Zobel (1991) noted that one of the tasks required to breed for non-conventional agricultural environments is to develop a series of test plots that represent a target range of environments. This can be difficult and expensive. However, in the instance of Western Canada and specifically Central Alberta, if the majority of growers are switching to DS or MT, it may be best to use DS or MT as part of the growing and selection protocol of breeding programs, when developing cultivars for these growers.

Wright (1976) described two basic philosophies held by plant breeders to deal with genotype by environment interactions. The basic options are to develop cultivars with adaptation to a variety of stresses within the target environments, or to divide the target environments into more homogeneous subsets in relation to the types of stress and then develop different cultivars for the subsets of various environments. As the nature of the genotype by environment interaction becomes more unpredictable, the efficiency of the use of a single environment to select for broad adaptation would be reduced. The use of a large number of selection environments that more adequately represented the target environments would increase this efficiency.

Factors such as soil temperature, soil moisture content, nutrient deficiency, and soil-borne disease, have been proposed to explain yield reductions under no-till management when compared to conventional tillage (Hwu and Allan 1992). Reduced tillage generally results in cooler soil temperatures early in the spring, thus effectively shortening the growing season and making earlier maturing cultivars desirable.

Francis (1991) noted that a feature of reduced tillage is the presence of greater amounts of crop residues on the soil surface causing cooler soil conditions. This feature may require a plant breeding solution of selecting for increased seedling vigor as a result of early cold stress tolerance and the ability to emerge through a residue covered soil. Hucl and Baker (1990) reported cultivar by environmental interactions for tiller numbers and time of tiller development when four spring wheat cultivars were subjecting to contrasting temperature regimes (10/5 and 20/10 degrees C). Because of temperature differences in seedbeds for DS compared to CT, tillering development could be a factor when selecting cultivars for DS. Lower yields of DS seeded winter wheat in the Pacific Northwest, U.S. may be due to poor tiller initiation in the cooler, and more shaded seedbed compared to conventional tillage (Rasmussen 1993). It has been suggested that in order for yields under DS to be equivalent to conventional tillage the above noted stresses must be tolerated. Breeding and selection for winter wheat more tolerant of these stresses could be beneficial for farmers wanting to use DS because of improved erosion control as well as reduced fuel and labor costs.

The genetic variability for adaptation of existing wheat genotypes to DS management has not been fully documented (Hwu and Allan 1992). The reduced yields sometimes observed may be the result of the tested genotypes having originated under conventional tillage and consequently lack fitness to the DS environment. Seedling vigor, foliar disease resistance, and early maturity are desirable traits of wheats grown under DS.

Moes and Domitruk (1995) observed differences among cultivars of the same crop species as far as their competitiveness with weeds when DS was used. They recommended that numerous trials over multiple years and numerous sites were necessary before any firm conclusions could be made.
There is potential for cultivar improvement via plant breeding for adaptation to alternative cropping systems (Smith and Zobel 1991). This potential is largely untapped. Sets of testing environments for doing this should be carefully chosen. A key question is whether the improvement that can be made justifies the added effort and expense necessary. Experimental evidence to answer this question needs to be accumulated.

To produce some of the needed evidence for Central Alberta conditions, experiments were designed and conducted to test the validity of the hypothesis that CT, MT, and DS affect the yield of selected cultivars within a crop species differently and that interactions between tillage systems and crop cultivars exist. The objective of this set of experiments was to observe whether or not there are significant interactions between tillage systems and cultivars within three selected crop species, under two different Central Alberta sites for each crop species. If interactions did occur, then determine which cultivars were most affected by the tillage systems in relation to the other cultivars of the same crop species. The comparison within each experiment was made between the tillage systems and crop cultivars within a single species not among different crop species

2.2 Materials and Methods

2.2.1 Experimental Designs, and Statistical Analyses

A factorial design with four replicates was used for all the field experiments. The factors were three tillage systems (CT, MT, and DS), and crop cultivars (nine cultivars for the barley, five for the canola, and four for the field pea). In 1991 a randomized complete block (RCB) design was used for the barley cultivars and a split-block (SB) design for the canola cultivars. In 1992 a SB design was used for both the two barley and the two canola sites. The SB design was used for the barley experiment in 1993. The SB design was more feasible to use because of the field scale equipment used in the seedbed preparation and seeding of the individual plots. There was a more even seeding of the cultivar seeds with the longer seed drill runs as part of a SB design as opposed to a RCB. A split-plot (SP) design was used for the field pea experiments that were conducted in 1994 and 1995. In all cases of the SB and SP designs tillage system was the main plot and cultivar type as the sub-plot. All the experiments were grouped together as appropriate to analyze for the affect of site-year as a factor. This included the analyses for the Barley experiments. The RCB and the SB experiments were grouped separately, with the two RCB experiments done in 1991combined and analyzed together, and the three SB experiments, two done in 1992 and one done in 1993 combined and analyzed together. The four site-years for the canola experiments were all SB designs and were combined together for analysis. The three site-years for the field pea experiments were all SP designs and were combined together for analysis. In the results sections of this chapter the combined analysis including the factors of site-year, crop cultivar and tillage system are first reported, followed by further analysis done for two of the barley experiment site-years and one of the canola experiment site-years where tillage system x cultivar interactions were noted. All statistical analyses were Analysis of Variance (ANOVA). Three-way analysis was done for the combined analyses to include site-year, cultivar and tillage system factors, and two-way analysis were done for the analyses that were done to determine the significance of the tillage system x cultivar interaction for individual site-years where this occurred. Mean differences among site-years, tillage systems, or cultivar types were compared using Student Newman Kuels test at P=0.05, unless otherwise noted (CoStat 1995). In the cases of statistically significant interactions of the factors of tillage system and cultivar, the comparisons of interest were analyzed using an LSD test with Least Squares Means (SAS 1989).

2.2.2 Crop Species and Cultivar Descriptions, Sites, Soils, and Climate

Barley (*Hordeum vulgare*), canola (*Brassica napus*), and field pea (*Pisum sativum*, var. *arvense*) were grown using three different tillage systems (i.e. CT, MT, and DS) during the years 1991, 1992 and 1993 for five site-years for barley, during the years 1991 and 1992 for four site years for canola, and years 1994 and 1995 for three site-years for field pea at two separate sites for each crop species. The various cultivars within each crop species were chosen with the goal of trying to include as much genetic variability as reasonably available within existing registered cultivars in Western Canada. For example in the barley species, cultivars were selected that have contrasting characteristics such as tall, medium, and semi-dwarf height; two and six-row growth habit; malting and feed or general use type, and differences in maturity. In the canola species, cultivars were selected that represented different genotypic ancestry, and one of the cultivars is a hybrid first generation cross from two parental lines (Hyola 401). In the field pea species there were differences in average yield potential, days to maturity, length of vine and seed color and size. The cultivars for the various crop species are described below in separate tables for each species.

Table 2.1 Canola cultivar descriptions, used in the cultivar by tillage interaction experiments, as provided by Alberta Agriculture, Food and Rural Development 1991.

Cultivar Name	Genotype	Relative Yield, % of Legend	Relative Maturity to Legend	Relative Straw Strength	Relative Oil Content, % of Legend
Legend	Pure Line	100	104 days	Good	43.3
Alto	Pure Line	111	-2	Fair	+ 1.5
Bounty	Pure Line	102	+2	Good	0.0
Hyola 401	Hybrid	122	+1	Excellent	+ 0.7
Westar	Pure Line	96	0	Fair	+ 1.0

Table 2.2 Barley cultivar descriptions, used in the cultivar by tillage interaction experiments, as provided by Alberta Agriculture, Food and Rural Development 1991.

Cultivar Name	Use, Malt(M) or General use as Feed(F)	Relative Yield % of Leduc Cultivar	Row Number / Hulled(H) or Hulless(N)	Relative Maturity, compared to Harrington	Height cm / Lodging Resistance
Leduc	F	100	6 / H	- 2	79 / Fair
Abee	F	97	2 / H	+ 1	77 / Good
Bonanza	M	91	6 / H	- 1	93 / Fair
Condor	F	78	2 / N	0	75 / V. Good
Duke	F	104	6 / H	+ 2	74 / Excellent
Heartland	F	99	6 / H	0	74 / V. Good
Harrington	M	86	2 / H	97 days	76 / Fair
Noble	F	103	6 / H	- 2	82 / Good
Virden	F	101	6 / H	+ 4	86 / Good

Table 2.3. Field Pea Cultivar Descriptions, used in the cultivar by tillage interaction experiments, as provided by Alberta Agriculture, Food and Rural Development 1994.

Cultivar Name	Relative Yield % of Radley	Days to Maturity	Seed wt. (g/1000) / Seed color	Vine Length
Radley	100	105	199 / Green	71
Highlight	112	111	200 / Yellow	82
Montana	116	109	278 / Yellow	68
Patriot	107	105	211 / Yellow	73

The two barley sites were at Ellerslie (three years), and Wainwright (two years), the two canola sites were at Calmar (two years) and Strome (two years), and the two field pea sites were at Edmonton (two years) and Warburg (one year).The soils at the sites are all Black Chernozemic, with the exception of the Warburg site that is Gray Luvisolic as determined by examining soil profiles at the sites using criteria based on the Canadian system of soil classification (Canada Soil Survey Committee 1978). The textures ranged from a clay soil to a sandy-loam (Table 2.4.).

Table 2.4. Years of research, soil type, texture, pH, altitude, and latitude and longitude for experimental sites, used in the cultivator by tillage interaction experiments.

Site Name	Years	Soil Subgroup	Texture	pH	Altitude m	Latitude / Longitude
Ellerslie	91, 92, 93	Orthic Black Chernozemic	Clay	6.2	715	53° 30' N / 113° 24' W
Edmonton	94 and 95	Orthic Black Chernozemic	Clay	6.2	715	53° 34' N/ 113° 34' W
Wainwright	91 and 92	Orthic Black Chernozemic	Sandy - Loam	5.9	686	52° 53' N/ 110° 48' W
Calmar	91 and 92	Gleyed Black Chernozemic	Clay - Loam	6.2	725	53° 20' N/ 114° 00' W
Strome	91 and 92	Solonetzic Black Chernozemic	Clay - Loam	6.5	689	53° 13' N/ 112° 00' W
Warburg	95	Orthic Gray Luvisol	Clay - Loam	6.0	823	53° 17' N/ 114° 27' W

2.2.3 Tillage Systems and Field Operations

The tillage systems used were slightly different among the barley, canola, and field pea crop species, as explained below:

- DS was the same under all the experiments. Canola, barley or field pea were directly seeded into wheat stubble with no prior tillage. ROUNDUP (Glyphosphate) herbicide (2.5 L ha^{-1}) was applied two days prior to seeding.

- MT for the barley and field pea experiments consisted of one cultivation (chisel plow operation at 254 mm spacing using 300 mm sweeps, with attached spring-tooth harrows) prior to seeding. For canola there was one cultivation as above, then an application of EDGE (Ethylfluralin) herbicide (dispersible concentrate 0.77 kg ha^{-1}), followed by a second cultivation after applying the herbicide, then a third cultivation a few days later to achieve adequate incorporation of the herbicide.

- CT for all the three crop species started with a cultivation with a chisel plow with sweeps, with no harrows attached, in the fall of the previous year after harvesting the wheat crop. In the spring of the following year there was a double disc operation then two cultivations with the chisel plow with sweeps with spring-mounted tine harrows. The canola plots had an application of EDGE herbicide after the discing but prior to the last two cultivations.

The amount of tillage used affects how much of the previous crop residue is left on the soil surface. The more tillage, the less residue is left on the soil surface. Figure 2.1 below is a picture of one of the blocks of research plots taken after seeding in the spring.

The crops were seeded at 38, 51, and 51 mm depth respectively for the canola, barley, and field pea. A John Deere 752 series conservation tillage drill was used to band the nitrogen fertilizer and seed the crops (Figure 2.2). The seeding was done perpendicular to and after banding of the nitrogen fertilizer.

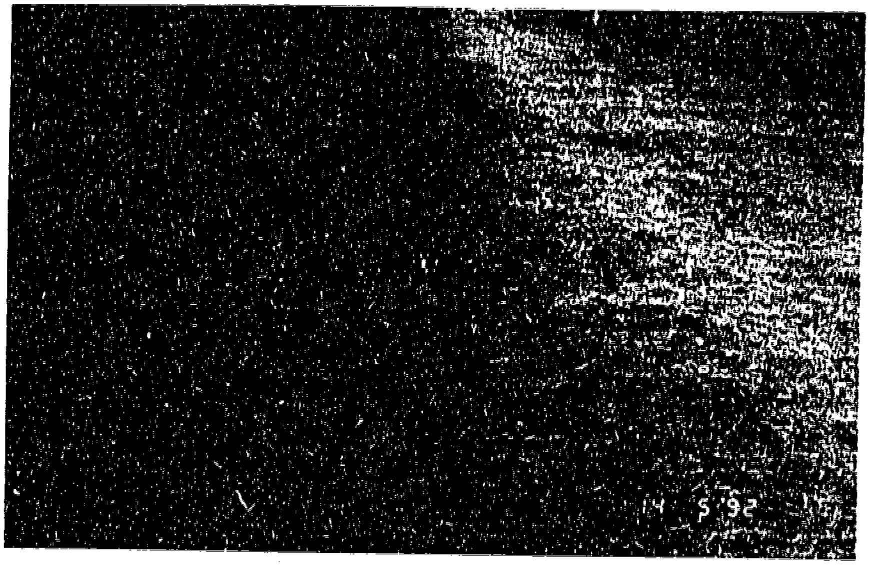

Figure 2.1. Block of research plots, showing the split between CT on the left and DS on the right. Ellerslie site, May 1992.

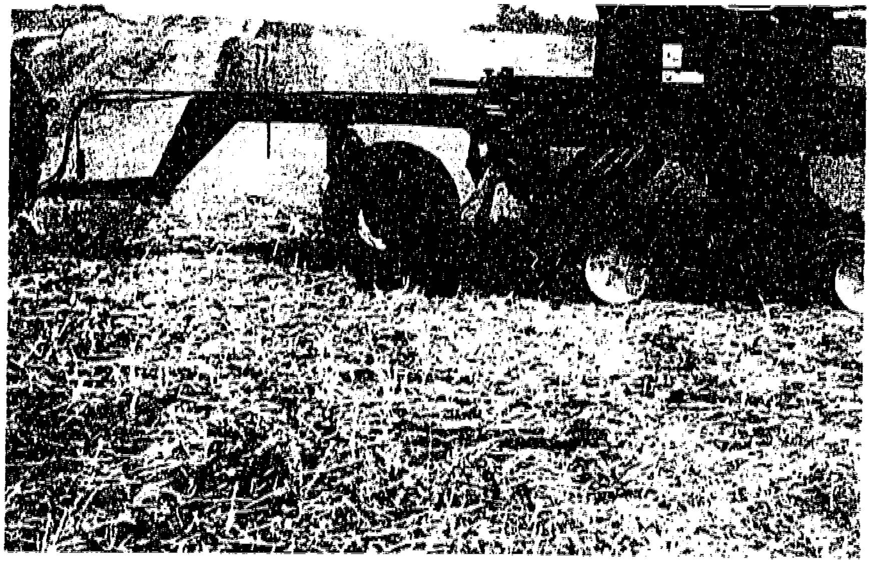

Figure 2.2. The John Deere 752 seed drill seeding the research plots at Wainwright, AB, May 1992.

The John Deere 752 seed drill uses a single disc opener operating at a seven degree angle to direction of movement. The seed or fertilizer is placed in the slot opened by the disk using a seed boot on the non-soil engaging side of the disk. A packing wheel pushes the seed or fertilizer into firm soil in the furrow and a closing wheel pulls loose soil over the furrow.

The rate of the banded nitrogen fertilizer was 80 kg N ha^{-1} in the form of urea, except for the field peas that received no nitrogen as banded urea, but did receive 6.6 kg N ha^{-1} in the starter fertilizer applied in the seed row. Starter fertilizer was applied with the seed of all the crop species at 60 kg product ha^{-1}, mono-ammonium phosphate. The barley and canola crop seeds were treated with Vitavax seed treatment prior to seeding. The field pea was inoculated with NITRAGEN, a peat based rhizobia inoculant, after moistening the seed with skim milk.

The canola crop received an application of LONTREL herbicide (990 ml ha^{-1}) for perennial thistle control (Canada Thistle [*Cirsium arvense*] and Perennial Sow Thistle. [*Sonchus arvensis*]) at the six leaf stage of the canola at the Strome site in 1991 and 1992. No LONTREL was applied at the Calmar site during the two years. Thistle growth at this site, especially under no-tillage in 1992 did affect yields. This will be discussed in the results section below. The barley plots received an application of HOEGRASS II herbicide (3.5 L ha^{-1}) each year for broadleaf and grassy weed control, when the barley was at the four leaf stage, for control of broadleaf weeds and wild oat (*Avena fatua*). The field pea experiment received an application of PURSUIT herbicide (4.0 L ha^{1}) for control of selected grassy and broadleaf weeds.

2.2.4 Measurements and Plot Sizes

One m^{2}, yield samples were taken randomly from near the center of the plots at crop maturity. The yield measurements taken or calculated were total sample weight (total wt.), grain yield, and straw yield and harvest index (grain yield/total wt.). The plot sizes for the various experimental designs were as follows:

- RCB, barley cultivars, three m wide and ten m long, an individual block was ten m wide and 81 m long.
- SB, barley cultivars, the three tillage strips were five m wide by 54 m long, the cultivars strips were six m wide and 15 m long, an individual block was 15 m wide by 54 m long.
- SB, canola cultivars, the three tillage strips were five m wide by 15 m long, the cultivars strips were three m wide by 15 m long, an individual block was 15 m wide by 15 m long.
- SP, field pea cultivars, the tillage or main plots were 12 m wide by 12 m long, the cultivar split-plots were three m wide by 12 m long.

2.3 Results and Discussion

The weather is a significant factor in evaluating the effects of tillage systems on crop growth. If weather conditions are warm and dry, DS and MT tend to conserve moisture compared to CT, and the yield under DS and MT can be greater than CT. If weather conditions are cool and moist, the inverse occurs and DS and MT will often result in lower yields than CT (Ullrich and Muir 1986, Holland and Herridge 1992). This is in part due to the faster emergence under the warmer seedbed conditions under CT compared to DS conditions, and if moisture is in an excess supply the greater evaporative losses of moisture resulting from CT compared to DS may be beneficial to crop emergence. If weather conditions are moderate, that is with adequate, but not excessive moisture, and favorable temperatures, the yields of the three tillage systems, CT, MT, and DS will tend to be similar.

The weather experienced at each of the site-years as well as the 30-year average is reported below (Table 2.5).

Table 2.5. Weather characteristics of experimental sites, used in the cultivar by tillage interaction experiments.

Site-Year	30 yr. Avg. *, Precipitation, May to Sept.,(mm)	Actual Precipitation, May to Sept., (mm)	30 yr. Avg. *Daily Temperature, May to Sept., °C	Avg. Daily Temperature, May to Sept., °C
Ellerslie 91	337	309	13	14
Ellerslie 92	337	215	13	12
Ellerslie 93	337	276	13	13
Wainwright 91	313	244	14	15
Wainwright 92	313	185	14	13
Calmar 91	381	384	14	14
Calmar 92	381	229	14	12
Strome 91	263	358	14	15
Strome 92	263	175	14	13
Edmonton 94	337	445	13	14
Edmonton 95	337	284	13	13
Warburg 95	374	370	not available	13

Source: Environment Canada. * 1961-1990.

The amount of residue on the soil averaged close to 80% for DS, 40% for MT, and 15% for CT. Both DS and MT are considered a form of conservation tillage because residues are maintained greater than 30%. A 30% residue level is considered a level of residue cover that will prevent serious soil erosion from the action of wind or water (Hudson and Harsch 1991). Each of the research sites were monitored to be sure that the residue levels met the criteria as described above. The point interception method was used to measure the residue cover (Wollenhaupt and Pingry 1991). This was done using a meter long stick with marks every ten cm. The stick was tossed randomly near the center of the plot area and then the number of times a piece of straw or chaff is directly below one of the marks was recorded. If there was residue at six out of the ten marks, and bare soil at the remaining four marks, then a 60% residue cover level would have been recorded.

2.3.1 The Effect of Tillage System on the Growth and Yield of Canola

The objective of these canola experiments was to determine whether there was an interaction between tillage system and canola cultivar type. However the large effect of site-year was clearly a factor affecting the results. The four site-years were combined and analyzed as a three-way ANOVA looking at the factors of site-year, cultivar and tillage system. An example of the analysis for total weight is shown below (Table 2.6).

There were differences among site-years for the canola harvest measurements of total weight, grain yield and straw yield (Table 2.7). This is due to the unique weather conditions experienced at each site and each year. Site-years at the same location can be considered as separate environments (Romagosa and Fox 1993), and the site-years were analyzed separately and not further grouped to look at location differences. There were overall differences among tillage systems for total weight, grain yield, and straw yield. There were no differences among tillage systems for harvest index. There were differences observed among canola cultivars for the harvest measurements of total weight, and straw yield, and significant tillage system by cultivar interactions were observed for harvest index only. There was a significant interaction between the factors of site-year and tillage system for all measurements but harvest index. However there was no interaction between site-year and cultivar, as well as no three-way interaction of the factors. The differences between site-years resulted from the different weather and other site factors at each site interacting with the canola cultivars as grouped by tillage system, more than among the cultivars.

Table 2.6 Three-way ANOVA printout for total weight of canola; SB design; three factors: site-year, tillage system and canola cultivar; four site-years: Calmar 1991, Calmar 1992, Strome 1991 and Strome 1992.

ANOVA Printout

Ordinary ANOVA - Treating site-year as random

General Linear Models Procedure

Dependent Variable: TOTAL WEIGHT

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	143	6684746.9798	46746.4824	2.25	0.0001
Error	96	1994633.3894	20777.4311		
Corrected Total	239	8679380.3692			

R-Square	C.V.	Root MSE	TOTAL WEIGHT Mean
0.770187	23.91355	144.14379	602.77028

Source	DF	Type III SS	Mean Square	F Value	Pr>F
Site year	3	349635.7389	116545.2463	5.61	0.0014
Tillage	2	391989.1936	195994.5968	9.43	0.0002
Cultivar	4	188709.4694	47177.3674	2.27	0.0672
Tillage x cultivar	8	229567.2521	28695.9065	1.38	0.2145
Site year x tillage	6	335410.7988	55901.7998	2.69	0.0186
Site year x cultivar	12	299657.7034	24971.4753	1.20	0.2931
Site year x tillage x cultivar	24	520744.1851	21697.6744	1.04	0.4212
Site year x replicate	12	1912565.3128	159380.4427	7.67	0.0001
Site year x tillage x replicate	24	1206430.8899	50267.9537	2.42	0.0013
Site year x cultivar x replicate	48	1250036.4357	26042.4257	1.25	0.1740

Table 2.7. Summary of ANOVA, four site-years, five canola cultivars, and three tillage systems.

Source of Variance	DF	Yield Measurement	F Value	Significance
Site-Year	3	Total Weight	5.61	0.0014
		Grain Yield	4.87	0.0034
		Straw Yield	5.40	0.0018
		Harvest Index	0.74	0.5291ns
Tillage System	2	Total Weight	9.43	0.0002
		Grain Yield	8.43	0.0004
		Straw Yield	8.95	0.0003
		Harvest Index	0.74	0.4810ns
Cultivar	4	Total Weight	2.27	0.0672
		Grain Yield	1.75	0.1458ns
		Straw Yield	2.41	0.0543
		Harvest Index	1.49	0.2127ns
Tillage x Cultivar Interaction	8	Total Weight	1.38	0.2145ns
		Grain Yield	1.66	0.1175ns
		Straw Yield	1.28	0.2635ns
		Harvest Index	2.00	0.0541
Site-Year x Tillage Interaction	6	Total Weight	2.69	0.0186
		Grain Yield	2.67	0.0193
		Straw Yield	2.52	0.0263
		Harvest Index	0.63	0.7035ns
Site-Year x Cultivar Interaction	12	Total Weight	1.20	0.2931ns
		Grain Yield	1.19	0.2980ns
		Straw Yield	1.19	0.3046ns
		Harvest Index	1.24	0.2702ns
Site-Year x Tillage x Cultivar Interaction	24	Total Weight	1.04	0.4212ns
		Grain Yield	0.85	0.6642ns
		Straw Yield	1.08	0.3813ns
		Harvest Index	0.76	0.7758ns

ns = not significant

The effects of tillage, cultivar type and any tillage by cultivar (TxC) interactions for each of the four individual site-years are summarized below (Table 2.8). Only the Strome site in 1991 showed TxC interactions. There were some differences among cultivars and/or tillage systems observed in the other three site years.

The TxC interactions observed at the Strome site 1991 were the result of some of the cultivars responding differently to the three tillage systems. For total weight, two cultivars responded in a contrasting manner. Alto displayed a higher weight under CT compared to both MT and DS. In contrast Bounty had lower weights for CT and MT compared to DS. Hyola 401 displayed lower yields under DS compared to MT. Legend and Westar displayed no differences among tillage systems (Table 2.9).

Table 2.8. Summary of ANOVA, two sites, and two years, for five canola cultivars and three tillage systems.

Source of Variance	Yield Measurement (t ha^{-1}, except Harvest Index that is a ratio.)	Calmar 1991	Calmar 1992	Strome 1991	Strome 1992
Tillage (T)	Total weight	ns	*	ns	**
	Grain yield	ns	*	ns	**
	Straw yield	ns	*	ns	***
	Harvest index	ns	*	ns	***
Cultivar (C)	Total weight	ns	*	ns	ns
	Grain yield	ns	*	ns	ns
	Straw yield	ns	*	ns	ns
	Harvest index	**	*	ns	**
TxC Interaction	Total weight	ns	ns	*	ns
	Grain yield	ns	ns	*	ns
	Straw yield	ns	ns	*	ns
	Harvest index	ns	ns	ns	ns
Coefficient of Variation, %	Total weight	27.1	25.5	18.1	26.2
	Grain yield	34.5	30.4	26.5	29.4
	Straw yield	26.0	24.8	17.3	25.9
	Harvest index	13.8	10.9	15.8	10.3

ns= not sig., * sig. at P=0.05, ** at P=0.01, and *** at P=0.001

Table 2.9. Canola total weight (t ha $^{-1}$) harvest measurements. for five cultivars and three tillage system, Strome site 1991.

Cultivar	Tillage System		
	CT	MT	DS
Alto	7.1 a	5.1 b	4.7 b
Bounty *	4.5 b	6.0 a	6.0 a
Hyola 401 *	5.7 a	6.3 a	4.9 b
Legend	5.6 a	6.9 a	6.7 a
Westar	5.4 a	6.1 a	4.8 a

Different letters within a row indicate a difference among tillage systems at $P = 0.05$, or * $P = 0.10$.

Similar differences among tillage systems were observed for the various cultivars for grain and straw yield. The cultivar Alto seemed most affected by tillage system as it was similar in yield compared to other cultivars under CT for grain yield and straw yield, and lower yielding than other cultivars under MT and DS. Bounty tended to have lower grain yield and straw yield for CT compared to MT and DS. Legend showed a lower straw yield for CT compared to MT and DS. The remaining cultivars, Hyola 401 and Westar displayed little differences among tillage systems (Table 2.10).

Table 2.10. Canola cultivar grain yield, and straw yield (t ha^{-1}), by tillage system, Strome site, 1991.

Cultivar	Grain Yield			Straw Yield		
	CT	MT	DS	CT	MT	DS
Alto	1.5 a	1.0 b	0.9 b	5.6 a	4.1 b	3.8 b
Bounty	1.0 a	1.3 a	1.3 a	3.6 b *	4.7 a	4.7 a
Hyola 401	1.0 a	1.2 a	0.9 a	4.7 a	5.1 a	4.0 a
Legend	1.3 a	1.2 a	1.4 a	4.3 b	5.6 a	5.3 a
Westar	1.0 a	1.4 a	1.0 a	4.4 a	4.7 a	3.9 a

Different letters indicate difference among tillage system by cultivar combination, $P = 0.05$, or * $P = 0.10$. Comparisons within an individual cultivar, and harvest measurement only.

The tillage system differences observed at the Strome site in 1992, are attributed to greater moisture stress on the crop. The moisture received at the site was 67% of the 30 yr. average (Table 2.5). The moisture conserving benefit of DS compared to MT or CT would account for the difference in yields as affected by tillage system (Table 2.11). This site is a useful example of the effect of weather and the relative yields of the different tillage systems. In 1991 the precipitation was 136% of the 30 yr. average, and CT yielded higher than DS, 6.1 t ha^{-1} compared to 5.4 t ha^{-1} respectively. In the drier year of 1992, when the precipitation was 67% of the 30 year average, DS out yielded CT and MT. This switch in the relative yields among tillage systems is similar to the result of 10 barley genotypes grown under CT, MT, and DS in eastern Washington. Ullrich and Muir (1986) observed that in a relatively moist year, CT yields were greater than DS. However, in a dry year, DS yields were greater than CT. Early crop growth has been shown to be retarded by a surface mulch of residue, as present in DS culture, due to cooler soil temperatures. However later in the life cycle of the crop the crop residues on the soil surface conserve soil moisture that can result in increased crop yields (Wicks et al. 1994).

Table 2.11. Tillage System Effects on Canola Harvest Measurements. Strome 1992

Tillage System	CT	MT	DS
Total Weight t ha-1	5.6 b	5.5 b	7.0 a
Grain Yield t ha-1	1.1 b	1.1 b	1.5 a
Straw Yield t ha-1	4.5 b	4.4 b	5.5 a
Harvest Index	0.20 a	0.19 a	0.21 a

Different letters within each row or harvest measurement indicate difference at P = 0.05.

Differences among tillage systems at Calmar in 1992 were due to poor thistle control, mostly sow thistle (*Sonchus arvensis*) under DS compared to MT or CT, even though the site also tended to be drier than normal (Table 2.5). The yields for grain were respectively 2.0 t ha^{-1}, 1.9 t ha^{-1}, and 1.2 t ha^{-1} for MT, CT and DS. The site was seeded early and the sow thistle seedlings had not emerged sufficiently to absorb the pre-seeding herbicide (ROUNDUP 2.5 L ha^{-1}). The pre-seeding tillage operations under MT and CT controlled the thistle growth sufficiently, as noted by visual observation, to allow the canola to become better established and be little affected by the thistles.

2.3.2 The Effect of Tillage System on the Growth and Yield of Barley

The objective of these experiments was to determine whether or not there was an interaction between tillage system and barley cultivar type. The five site-years of data were grouped together as appropriate for the RCB and the SB designs. Examples of the ANOVA printouts for total weight for each of the designs are shown below. Table 2.12 is for the RCB design, and Table 2.13 is for the SB design.

The combined analysis for the RCB design for the two barley site-years in 1991 showed no tillage by cultivar interaction. The site-years, tillage and cultivar factors were all significant. A significant interaction shown in the analysis was the site-year by cultivar interaction. The effects of site-year and cultivar factors were large and the tillage by cultivar interaction was minor in effect.

The combined analysis for the three site-years of barley where the SB design was used, also had no significant tillage by cultivar interaction. The factors of site-year, tillage, and cultivar were all significant. The interactions of site-year with both tillage and cultivar were significant. Additionally the three-way interaction of site-year by tillage by cultivar was significant within a probability of 0.01. Thus both combined analyses for the barley cultivar and tillage system experiments indicate that the site-year factor had a major effect and that any tillage by cultivar interactions observed at two of the five barley sites are not predictable and of minor effect.

Table 2.12. Three-way ANOVA Printout for Total Weight of Barley; RCB Design; Three Factors: Site-year, Tillage System and Barley Cultivar; Two Site-years: Wainwright 1991 and Ellerslie 1991

Ordinary ANOVA, Treating site-year as random

General Linear Models Procedure

Dependent Variable: TOTAL WEIGHT

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	59	1636802.6721	27742.4182	3.86	0.0001
Error	156	1121511.9721	7189.1793		
Corrected Total	215	2758314.6442			

R-Square	**C.V.**	**Root MSE**	**TOTAL WEIGHT Mean**
0.593407	17.02986	84.789028	497.88454

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Site year	1	568500.44535	568500.44535	79.08	0.0001
Tillage	2	45321.02016	22660.51008	3.15	0.0455
Cultivar	8	250481.00993	31310.12624	4.36	0.0001
Tillage x cultivar	16	143528.42824	8970.52677	1.25	0.2381
Site year x tillage	2	2801.22451	1400.61225	0.19	0.8232
Site year x cultivar	8	231999.18272	28999.89784	4.03	0.0002
Site year x tillage x cultivar	16	77941.53489	4871.34593	0.68	0.8129
Site year x replicate	6	316229.82625	52704.97104	7.33	0.0001

Table 2.13 Three-way ANOVA printout for total weight of barley; SB design; three factors: site-year, tillage system and barley cultivar; three site-years: Wainwright 1992, Ellerslie 1992 and Ellerslie 1993

Ordinary ANOVA, Treating site-year as random

General Linear Models Procedure

Dependent Variable: TOTAL WEIGHT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	179	55916185.099	312380.922	18.22	0.0001
Error	144	2469043.670	17146.137		
Corrected Total	323	58385228.769			

R-Square	C.V.	Root MSE	TOTAL WEIGHT Mean
0.957711	14.01584	130.94326	934.25185

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site year	2	47363224.569	23681612.284	1381.16	0.0001
Tillage	2	238353.334	119176.667	6.95	0.0013
Cultivar	8	1298497.762	162312.220	9.47	0.0001
Tillage x cultivar	16	235489.921	14718.120	0.86	0.6177
Site year x tillage	4	255210.490	63802.623	3.72	0.0065
Site year x cultivator	16	987517.123	61719.820	3.60	0.0001
Site year x tillage x cultivator	32	769547 154	24048.349	1.40	0.0932
Site year x replicate	9	1579305.706	175478.412	10.23	0.0001
Site year x tillage x replicate	18	442554.050	24586.336	1.43	0.1242
Site year x cultivator x replicate	72	2746484.989	38145.625	2.22	0.0001

The effect of site-year was clearly a factor affecting the results. All site-years were combined and analyzed as a three-way ANOVA looking at the factors of site-year, cultivar and tillage system. Summaries of the results for all the yield measurements are shown below in the two following tables. Table 2.14 shows the results from the two RCB design experiments, and Table 2.15 shows the results from the three SB experiments.

Table 2.14. Summary of ANOVA, two site-years, randomized complete block design, nine barley cultivars, three tillage systems, and two sites (Wainwright 1991, and Ellerslie 1991).

Source of Variance	DF	Yield Measurement	F Value	Significance
Site-Year	1	Total Weight	79.08	0.0001
		Grain Yield	0.20	0.6518ns
		Straw Yield	235.06	0.0001
		Harvest Index	489.59	0.0001
Tillage System	2	Total Weight	3.15	0.0455
		Grain Yield	3.75	0.0257
		Straw Yield	2.37	0.0971
		Harvest Index	3.20	0.0434
Cultivar	8	Total Weight	4.36	0.0001
		Grain Yield	11.10	0.0001
		Straw Yield	4.51	0.0001
		Harvest Index	45.26	0.0001
Tillage x Cultivar Interaction	16	Total Weight	1.25	0.2381ns
		Grain Yield	1.24	0.2444ns
		Straw Yield	1.26	0.2294ns
		Harvest Index	1.58	0.0797
Site-Year x Tillage Interaction	[illegible]	Total Weight	0.19	0.8232ns
		Grain Yield	0.98	0.3783ns
		Straw Yield	0.09	0.9139ns
		Harvest Index	4.56	0.0118
Site-Year x Cultivar Interaction	8	Total Weight	4.03	0.0002
		Grain Yield	2.69	0.0084
		Straw Yield	5.03	0.0001
		Harvest Index	3.12	0.0027
Site-Year x Tillage x Cultivar Interaction	16	Total Weight	0.68	0.8128
		Grain Yield	0.92	0.5460
		Straw Yield	0.71	0.7841
		Harvest Index	2.11	0.0101

ns = not significant

Table 2.15 Summary of ANOVA, three site years, split block design, nine barley cultivars, three tillage systems and three sites (Wainwright 1992, Ellerslie 1992, and Ellerslie 1993).

Source of Variance	DF	Yield Measurement	F Value	Probability
Site-Year	2	Total Weight	1381.16	0.0001
		Grain Yield	1248.45	0.0001
		Straw Yield	1034.22	0.0001
		Harvest Index	21.00	0.0001
Tillage System	2	Total Weight	6.95	0.0013
		Grain Yield	9.20	0.0002
		Straw Yield	3.36	0.0376
		Harvest Index	0.92	0.4014ns
Cultivar	8	Total Weight	9.47	0.0001
		Grain Yield	16.26	0.0001
		Straw Yield	26.63	0.0001
		Harvest Index	87.81	0.0001
Tillage x Cultivar Interaction	16	Total Weight	0.86	0.6177ns
		Grain Yield	1.22	0.2588ns
		Straw Yield	0.65	0.8355ns
		Harvest Index	1.77	0.0406
Site-Year x Tillage Interaction	4	Total Weight	3.72	0.0065
		Grain Yield	4.79	0.0012
		Straw Yield	2.11	0.0826ns
		Harvest Index	0.81	0.5238ns
Site-Year x Cultivar Interaction	16	Total Weight	3.60	0.0001
		Grain Yield	6.87	0.0001
		Straw Yield	4.13	0.0001
		Harvest Index	8.23	0.0001
Site-Year x Tillage x Cultivar Interaction	32	Total Weight	1.40	0.0932ns
		Grain Yield	1.26	0.1843ns
		Straw Yield	1.26	0.1815ns
		Harvest Index	1.58	0.9615ns

ns = not significant

The five individual site years of barley cultivars grown using three tillage systems is summarized in Table 2.16. The Wainwright site showed TxC interactions in both 1991, and 1992. There were some differences among cultivars observed in all five site-years and among tillage systems in 1991 at the Wainwright site and in 1992 at the Ellerslie site.

Table 2.16 Summary of ANOVA, two sites, and three years, for nine barley cultivars and three tillage systems.

Source	Yield Measurement	Ellerslie			Wainwright	
		91	92	93	91	92
Tillage	Total weight	ns	*	ns	ns	ns
	Grain yield	ns	**	ns	*	ns
	Straw yield	ns	ns	ns	ns	ns
	Harvest Index	ns	ns	ns	*	ns
Cultivar	Total weight	*	ns	**	***	***
	Grain yield	***	**	**	***	***
	Straw yield	***	**	***	***	***
	Harvest Index	***	ns	***	***	***
TxC Interaction	Total weight	ns	ns	ns	ns	**
	Grain yield	ns	ns	ns	ns	**
	Straw yield	ns	ns	ns	ns	**
	Harvest Index	ns	ns	ns	**	ns
Coefficient of Variation , %	Total weight	17.1	12.4	11.9	16.8	22.1
	Grain yield	18.1	12.5	13.0	20.4	54.6
	Straw yield	17.4	15.9	12.5	17.2	22.4
	Harvest index	4.7	7.0	4.5	9.1	40.2

ns = not sig., * sig. at P =.05, ** at P =.01. and *** at P =.001

At the Wainwright site in 1991, there were interactions observed between tillage system and barley cultivars for harvest index. Five out of the nine cultivars exhibited differences among tillage systems for this measurement. DS resulted in lower harvest index compared to MT and CT, for the cultivar Noble (Table 2.17). CT resulted in a higher harvest index compared to MT and DS for the cultivars Bonanza and Condor. In contrast the cultivars Virden and Harrington had higher harvest indexes for DS compared to MT. Lastly Harrington had a lower harvest index for MT compared to CT and DS. The remaining three cultivars Heartland, Leduc, and Duke showed no differences among tillage systems.

Table 2.17. The effect of tillage system on the harvest index of nine barley cultivars, Wainwright 1991.

Barley Cultivar	CT	MT	DS
Abee	0.44 a	0.43 a	0.40 a
Bonanza	0.45 a	0.39 b	0.37 b
Condor	0.37 a	0.30 b	0.29 b
Duke	0.46 a	0.45 a	0.46 a
Harrington	0.39 a	0.35 b	0.41 a
Heartland	0.42 a	0.39 a	0.41 a
Leduc	0.44 a	0.46 a	0.43 a
No	0.44 a	0.44 a	0.38 b
Virden	0.40 ab	0.38 b	0.43 a

Different letters within a row or barley cultivar indicate difference at P = 0.05.

Interactions among tillage systems and barley cultivars were observed for total weight, grain weight and straw weight, at the Wainwright site in 1992. There were no TxC interactions observed for harvest index. The interaction trends were similar the harvest measurements noted above. No significant differences were observed among tillage systems for the cultivars Bonanza, Duke, and Harrington. Two cultivars, Abee and Condor, showed higher yields for CT compared to MT and DS for total weight and straw yield, and Abee additionally for grain yield. The remaining three cultivars Leduc, Noble, and Virden had higher yields under DS in most cases compared to CT. Heartland had greater amounts of total weight and grain yield for DS compared to MT (Table 2.18).

The only similarities between the two site-years where TxC interactions were observed for the cultivars Condor and Virden. Condor had a larger harvest index for CT compared to MT and DS at Wainwright in 1991 and also had a larger total weight and straw yield for CT compared to MT and DS at Wainwright in 1992 (Tables 2.17 and 2.18). In contrast, Virden appeared to do well under DS compared to MT and CT for harvest index at Wainwright in 1991, and for DS compared to CT in 1992 at Wainwright for total weight, grain yield, and straw yield (Table 2.18).

In four of the five site-years of barley cultivars grown under the three tillage systems, there were no significant TxC interactions for total weight, grain yield, and straw yield. This is similar to results by

Ullrich and Muir (1986) in eastern Washington where ten barley genotypes were shown to exhibit wide adaptation to CT, MT, and DS. No TxC interactions were observed in two site-years of research.

Table 2.18. The effect of tillage system on the selected harvest measurements of nine barley cultivars. Wainwright 1992. (g m^{-2})

Cultivar	Tillage System	Total Weight (g m^{-2})	Grain Yield (g m^{-2})	Straw Yield (g m^{-2})
Abee	CT	480 a	225 a	225 a
	MT	320 b	144 b	176 b
	DS	345 b	165 b	180 b
Bonanza	CT	365 a	188 a	177 a
	MT	420 a	212 a	208 a
	DS	320 a	155 a	165 a
Condor	CT	655 a	231 a	424 a
	MT	495 b	180 a	315 b
	DS	520 b	193 a	327 b
Duke	CT	320 a	160 a	160 a
	MT	380 a	202 a	178 a
	DS	365 a	193 a	172 a
Harrington	CT	370 a	174 a	197 a
	MT	410 a	192 a	218 a
	DS	375 a	174 a	201 a
Heartland	CT	515 ab	276 ab	240 a
	MT	465 b*	254 b	211 a
	DS	590 a	330 a	260 a
Leduc	CT	205 b*	102 b*	103 a
	MT	290 ab	143 ab	147 a
	DS	330 a	175 a	155 a
Noble	CT	195 b	113 b	82 b
	MT	415 a	226 a	189 a
	DS	410 a	234 a	177 a
Virden	CT	390 b	198 b	192 b
	MT	530 a	284 a	246 ab
	DS	590 a	313 a	277 a

Different letters within each column, or harvest measurement and cultivar combination indicate a difference among tillage systems at P = 0.05. * P = 0.10.

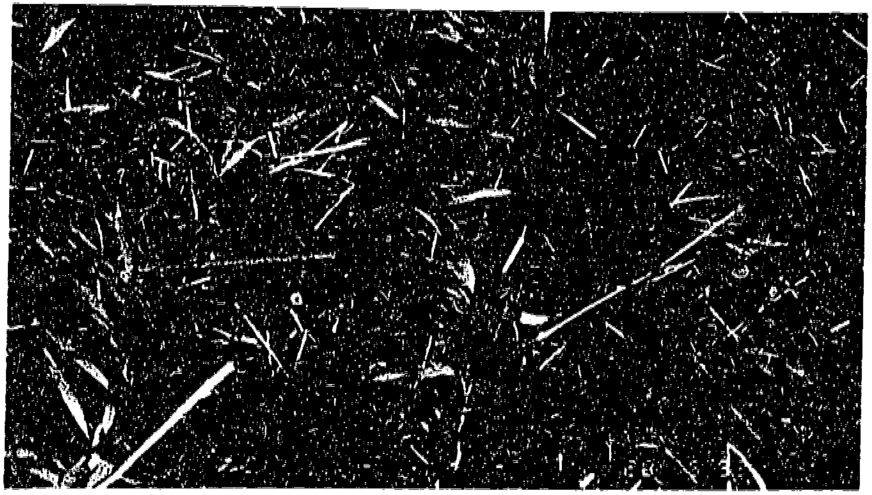

Figure 2.3. Barley seedlings in conventional tillage, Ellerslie, AB, 1993.

Figure 2.4. Barley seedlings in minimum tillage, Ellerslie, AB, 1993.

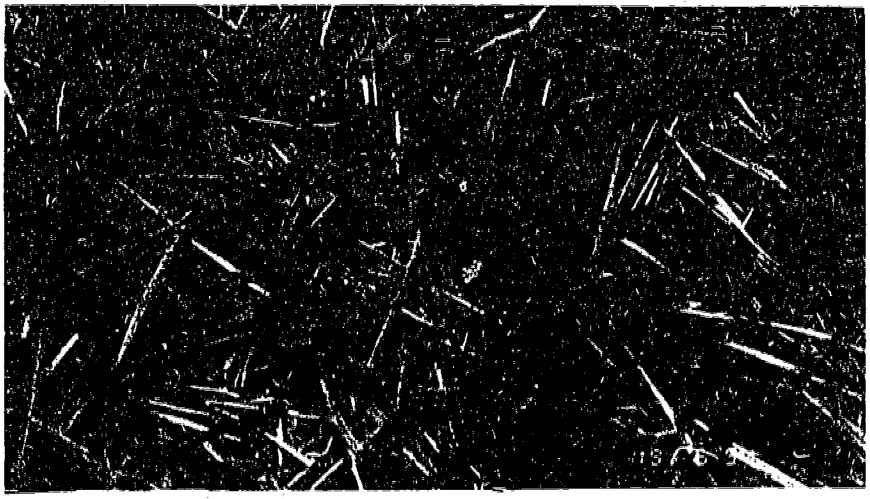

Figure 2.5. Barley seedlings in direct seeding, Ellerslie, AB, 1993.

2.3.3 The Effect of Tillage System on the Yield of Field Pea

The objective of these experiments was to determine whether or not there was an interaction between tillage systems and field pea cultivars. The three site-years of data were grouped together as appropriate for the SP design. Examples of the ANOVA printout for yield is shown below. (Table 2.19). When all three of the site-years are combined together and analyzed, there was a significant effect of field pea cultivars, but no overall significance of tillage system. Each site year was different enough so that the there was a significant difference among site-years. There were no interactions observed for site-year by tillage system, site-year by cultivar, tillage system by cultivar, and no three-way interaction of site-year by tillage system by cultivar.

Table 2.19. Three-way ANOVA Printout for Yield of Field Pea; SP Design; Three Factors: Site-year, Tillage System and Field Pea Cultivar; Three Site-years: Edmonton 1994, Edmonton 1995 and Calmar 1995.

Ordinary ANOVA, Treating site-year as random
General Linear Models Procedure
Dependent Variable: YIELD

R-Square	C.V.	Root MSE	TOTAL YIELD Mean
0.65284	26.248646%	80.0808417377	305.085611111

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Blocks	3	164287.9443	54762.648	4.13	0.0659
Site year	2	227641.5888	113820.79	8.59	0.0173
Site Error	6	79504.85165	13250.809		
Tillage	2	14006.59125	7003.2956	0.49	0.6233
Site year x tillage	4	12827.41106	3206.8528	0.22	.9225
Subplot error	18	259705.4932	14428.083		
Cultivar	3	57932.90125	19310.967	3.01	0.0348
Site year x cultivar	6	19152.06739	3192.0112	0.50	0.8083
Tillage x cultivar	6	65736.29314	10956.049	1.71	0.1295
Site year x tillage x cultivar	12	76046.19235	6337.1827	0.99	0.4674
Error	81	519448.2383	6412.9412		
Total	143	1496289.573			
Model	62	976841.3344	15755.505	2.46	0.0001

The average yields of the three site-years, the four field pea cultivars and the three tillage systems are shown below (Table 2.20). The Warburg 1995 site-year had the highest yields, followed by the Edmonton 1995 site-year, and last by the Edmonton 1994 site-year. When the pea cultivars are averaged over the three site-years the cultivar Radley yielded lower than the cultivar Highlight, and the other two cultivars were intermediate. This ranking is close to the relative yields obtained form Alberta Agriculture, Food and Rural Development (Table 2.3). The three tillage systems were similar in average yield.

Table 2.20. The yield of field pea by three site-year locations, field pea cultivar, and tillage system.

Factor and Groups within Factor	Field Pea Yield (t ha^{-1})
Site -year: Warburg 1995	3.6 a
Edmonton 1995	3.1 b
Edmonton 1994	2.7 c
Field Pea Cultivar: Highlight	3.3 a
Montana	3.1 ab
Patriot	3.0 ab
Radley	2.8 b
Tillage System: CT	3.2 a
MT	3.1 a
DS	2.9 a

Different letters within a factor indicate difference at P = 0.05.

At all three individual site-years there was a significant difference among field pea cultivars.(Table 2.21). At one of the site-years there was a significant difference among tillage systems. No significant TxC interaction was observed at any of the three site-years of research.

Table 2.21. Summary of ANOVA for field pea yields, two sites, and two years, for four field pea cultivars and three tillage systems.

Source of Variance	Edmonton 1994	Edmonton 1995	Warburg 1995
Cultivar	*	*	*
Tillage	*	ns	ns
TxC Interaction	ns	ns	ns
Coefficient of Variation, %	19.6	32.2	29.6

ns = not sig., * sig. at P =0.05

The results from the three site-years of experiments with field pea cultivars indicate that the field pea cultivars yielded similarly in relation to each other under the three tillage systems used. The mean yields from treatment classes for each of the three site-years are shown below (Table 2.22).

Table 2.22. Yield of field peas (t ha^{-1}) by site-years for cultivars and tillage systems.

Factor and Groups within Factor	Edmonton 1994	Edmonton 1995	Warburg 1995
Field Pea Cultivars	Montana 3.6 a	Montana 2.6 ab	Montana 2.3 b
	Highlight 3.5 a	Highlight 2.8 a	Highlight 2.7 a
	Radley 3.2 b	Radley 1.9 c	Radley 2.2 b
	Patriot 3.2 b	Patriot 2.2 bc	Patriot 2.7 a
Tillage Systems	CT 3.3 b	CT 2.4 a	CT 2.7 a
	MT 3.2 b	MT 2.4 a	MT 2.4 a
	DS 3.6 a	DS 2.4 a	DS 2.3 a

Different letters within a column of a factor and site-year combination indicate difference at P = 0.05.

Comparisons of this type among various tillage systems (e.g. CT, MT and DS) and cultivars within a crop species have been done in other areas. Cox and Shelton (1992) published results from North Dakota evaluating 14 winter wheat cultivars grown under both CT and DS. Their study showed TxC interactions for some quality parameters, however they concluded that for relative yields the cultivars performed similarly under DS compared to CT.

Preliminary results from the evaluation of maize cultivars under conventional and reduced tillage systems showed significant TxC interaction for stand establishment and yield (Smith and Zobel 1991). Certain cultivars better withstand the cool moist soil conditions and weed competition under reduced tillage compared to other cultivars. They maintain their relative yield rankings in both tillage systems, whereas other cultivars perform well under conventional management but perform poorly relative to other cultivars under reduced tillage. Wilhelm et al. (1991) reported research from Nebraska where TxC interactions were also observed for hybrid corn grown under contrasting tillage systems (CT, MT, and DS). They also concluded that even though TxC interactions were observed, relative yield comparisons would remain valid for all three tillage systems. It would appear that hybrid corn is one crop where more consistent and repeatable TxC interactions are obtained. This is perhaps due to the high heat-unit requiring nature of corn. Any slightly lower seed bed temperature for DS or MT compared to CT, will adversely affect early growth and grain yield (Swan et al. 1987). Earlier, in Manitoba, Wall and Stobbe (1983) suggested that a screening program for detecting suitable hybrids should be conducted if DS was to be used for corn production. This was because of the consistent TxC interaction observed for hybrid corn as affected by cooler seed bed temperatures when DS was used instead of CT. Other field crops are not as sensitive to seed bed temperatures.

Lueschen et al. (1991) reported similar results to above, that soybean can be grown using a wide range of tillage systems without serious yield consequences. In some site-years their research results showed TxC interactions, but no particular genotypic characteristic seemed to account for these interactions. It was thought that cultivars that perform well in a moldboard plow system or CT probably will perform well in a conservation tillage system, and that soybean cultivar evaluations using only conventional tillage were adequate. Researchers at the University of Tennessee studied whether tillage practice interactions are significant based on plant cultivar. They considered it important that crop producers know whether the cultivars recommended for CT are also productive under alternative tillage systems. (Graves et al. 1993). They concluded that soybean cultivars usually rank similarly when grown using CT or DS. When they conducted similar studies for hybrid corn, TxC interactions were observed in two out of five years. However it was concluded that hybrid cultivars that perform well under CT also perform well under DS, and that corn producers could use either tillage system and not sacrifice yield potential. Philbrook et al (1991) compared 12 soybean cultivars under CT, reduced tillage, and DS. They observed cultivar by site interactions for many growth characteristics. However the relative yield differences, did not change significantly among tillage treatments. It was concluded that selecting cultivars using yield performance data from CT evaluations could identify the best yielding cultivars for use in DS and reduced tillage.

O'Conner and Gusta (1993) reported a study conducted to determine the genotypic variability in the ability of seven flax (*Linum usitatissimum* L.) cultivars to germinate at low temperatures and also to emerge from a standard 20 mm depth or a deeper 40 mm depth. They summarized that flax lines could be selected for early emergence at low temperatures. This is pertinent information for flax producers who might be considering growing flax under reduced or DS cultural practices.

A total of 23 sorghum cultivars were compared under CT and DS in Tennessee. In most years there were few interactions between cultivar and tillage method (Graves and Bradley 1990).

Ciha (1982) studied the growth of four soft white spring wheat cultivars for three site-years using three tillage systems (CT, MT, and DS). TxC interactions were reported in all three site-years for grain yield. It was recommended that soft white spring wheat genotypes be evaluated for adaptation to specific tillage systems. Bauer and Black (1992) observed cultivar by tillage system interactions in four out of six years for pre-tillering plant populations, four out of eleven for head populations, and two out of nine for grain yields, when two spring wheat cultivars were grown under four different tillage systems in North Dakota. However there was no year-to-year consistency as to which cultivar was interacting with which tillage system. They mentioned that even though the cultivars appeared to respond differently from one another under a given seedbed condition, it did not seem to be predictable.

Allan and Peterson (1986) reported work that included comparative tests of cultivars, breeder lines, and genetic stocks of winter wheat under CT and DS. Based on 29 location-years, mean DS yields averaged 97% of means under CT practices. Of these site-years, only 36% resulted in significantly lower yields for the DS compared to CT. Significant TxC interactions occurred for yield and 15 other traits for 10% of the analyses. Yield rankings of the main soft white wheat were similar under DS and CT culture. It was concluded that significant genetic advance could be made for DS winter wheat yield performance based on CT yield trials and that a separate breeding program for reduced tillage seemed unjustified.

Hwu and Allan (1992) raised the point that most existing populations of agronomic crops lack sufficient genetic diversity to respond to natural selection for most traits affected by using conservation tillage systems. They attributed this to the high proportion of parentage used in developing most existing cultivars that has been derived from genotypes selected under CT husbandry. With populations of crops that have or will be intentionally developed to achieve a broader genetic base, evaluation under more than just CT may be justified. One example of this is the different ability of a group of genetically diverse barley cultivars that was evaluated for their ability to take up ammonium and nitrate in diurnally fluctuating root temperatures (Pan et al. 1991). A broad range of genetic diversity was selected by including spring barley types bred and selected in the Pacific Northwest (PNW), USA and in Scandinavia. Two soil temperature regimes, 9° C/5° C and 15° C/5° C were used to simulate soil temperatures characteristic of DS and CT respectively. It was concluded that the typically lower yielding Scandinavian genotypes had greater root growth along with greater ammonium and nitrate uptake compared to the PNW genotypes when grown using the cooler temperatures. The potential exists to cross the Scandinavian genotypes with the PNW genotypes and then back-cross with the PNW genotypes to obtain a higher yielding barley genotype that is better adapted to the cooler soil temperature regime of DS compared to CT.

2.4. Conclusions

The results of this study were that few observable interactions between canola and barley cultivar types and tillage systems exist. These interactions were observed in only one of the four site-years for the canola cultivars and two out of five site-years for the barley cultivars. The three-way combined analyses for the canola and barley experiments showed that the site-year factor had a great effect on the results and interacted significantly with one or more of the factors of tillage and cultivar. This indicates that the tillage system by cultivar interaction is difficult to observe and predict. No such interactions were observed for the field pea cultivars grown using the three different tillage systems at three site-years. This indicates that under most conditions the yields among cultivars of canola, barley, and field pea cultivars will be similar whether CT, MT or DS cropping systems are used.

This is useful information because it shows that cultivar breeding and evaluation procedures employed at this time in Central Alberta, and probably in similar regions in Western Canada, do not need to be radically changed due to the shift of growers from using CT to using MT or DS. The extra cost of running parallel evaluation trials of cultivars under CT, MT and DS at the same time is not warranted. Potential new cultivar releases grown and selected using CT will result in relative yield rankings that will be valid in the majority of cases even if the cultivars are grown under MT or DS and not CT. However, it is important to realize that initial selection for improved genotypes in segregating generations after crosses among parental lines could be done using CT, or MT, or DS culture. Perhaps the segregating generations after crosses could continue to be grown using CT. Subsequent yield trials could be conducted using MT or DS. In fact it may be advantageous to use MT or DS especially if the majority of growers in the target regions where the genotypes will be grown primarily use MT or DS cultural practices. This would help evaluate the potential new cultivars under growth conditions that the majority of growers use and should help give a more accurate evaluation of regional adaption.

2.5 References

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CHAPTER 3. THE EFFECT OF CULTIVAR RESIDUE TYPE ON THE GROWTH OF A SUBSEQUENT CROP GROWN USING CONVENTIONAL TILLAGE, MINIMUM TILLAGE, OR DIRECT SEEDING

3.1 Introduction

Residues of different crop species have been shown to have differential adverse allelopathic effects on the germination and early growth of a single crop species. Jessop and Stewart (1983) reported adverse allelopathic effects of rapeseed, sorghum, field pea, and wheat residues on the germination and early growth of wheat. The effects were observed up to 14 days after sowing, and were similar for two different soil sites, and for two temperature regimes (8 and 24° C). Research has shown that plant compounds, microbial modified plant compounds and microbial compounds contribute to allelopathic responses (Putman et al. 1990). Some of the types of compounds that are responsible for the adverse allelopathicity have been isolated and identified. Detailed analysis of extracts from wheat straw identified mostly phenolic acids, but also included other organic acids such as naphthoic acid, azelaic acid, and 1, 2, 3, 5-tetra bromobenzene as allelopathic compounds (Neves et al. 1990). Phenolic acids have also been identified in rye residues that could contribute to adverse allelopathic effects. However it has been demonstrated that, apart from phenolics, other unidentified water-soluble organic compounds were also responsible for the toxicity of rye decomposition products (Wojtkowiak et al. 1990).

There have been studies reported comparing the effects of residues from different crop and weed species, under different tillage systems, on subsequent crop growth and yield. Anderson (1993) reported some immobilization of soil nitrate, as well as increased allelopathic inhibition of grassy weed seedlings when winter wheat residue was shallowly incorporated , compared to leaving the residue on the soil surface. Blum et al. (1991 and 1992) reported greater concentration of potentially allelopathic compounds when soil extracts were taken from no-till soils compared to conventional till soils where wheat had been grown. In both no-till and conventional till soils the concentration of potentially allelopathic compounds was greater in the 0 to 2.5 cm core than the 0 to 10 cm core.

Some research has been done in Western Canada to study the effect of crop residues on subsequent crops. Freyman and Schaljc (1983) reported research studying the phytotoxic effects of winter wheat residue, that is worked down in the spring, on spring wheat and canola (*Brassica rapa*). Another example is the research of Gubbels and Kenaschuck (1989, 1) who reported the effects of residues of canola, barley, and flax on the growth of flax, and barley, with (CT) or without tillage (DS) prior to seeding. Under CT flax growth, the yield was lower with canola and flax residues, but little affected by barley residues. Under

DS, the flax yielded as well in the canola residues as the barley residues. DS tended to result in less adverse effects from the canola residues on flax growth compared to CT. The opposite was observed for two out of three years for the barley, where CT resulted in greater yields than DS, when the canola residues were present in the field. The two crop species, barley and flax, appeared to be affected by the canola residues differently when the two tillage systems were compared. Flax demonstrated better growth when the canola residues were left on the surface compared to incorporating the residue with tillage, while barley appeared to grow better when the canola residue was incorporated using tillage as opposed to leaving the residues on the surface. Only one cultivar of each crop species was used in these experiments, for the source of residue or the subsequent crop but the results indicate that the degree of allelopathic effects can be greatly affected by the tillage system used.

Not only has there been research into the effects of residues on the subsequent crops with and without tillage, but similar research was conducted to determine the effects of spring volunteer seedlings on the growth of the subsequent crops seeded in the same spring using different tillage systems (Gubbels and Kenaschuck 1989, 2). The growth of the volunteer seedlings was controlled by tillage for CT, and by an application of PARAQUAT under DS. Flax growth was decreased by the presence of canola and flax seedling residues, but little affected by barley seedling residue. Barley growth was reduced by canola, flax, and barley seedling residue. The overall growth of flax and barley was greater for DS compared to CT. Direct Seeding may have resulted in less inhibitive allelopathic effects from the volunteer seeding residues than CT, or higher yields for DS resulted from increased growth due to conservation of seedbed moisture for DS compared to CT. It is probable that the increased growth for DS compared to CT was due to both a reduction in allelopathic effects and an increased conservation of soil moisture.

Different cultivars within a single crop species can exhibit different reductions in growth in response to residues from a previous crop (Hicks et al. 1989, Kalburtji and Mosjidis 1993). Differential effects were observed for four cultivars of rye (*Secale cereale*) when grown with varying rates of residues of *Sericea lespedeza* (Kalburtji and Mosjidis 1993). However there was no interaction between residue rate and cultivars of ryegrass (*Lolium multiflorum*), or tall fescue (*Festuca arundinacea*). Selection of tolerant cultivars could be useful in promoting more rapid early growth (Caviness et al.1986). Hicks et al. (1989) conducted research to assess the allelopathic potential of wheat residues on cotton growth. Laboratory bioassays revealed that cotton seedling development was inhibited by aqueous extracts of wheat straw. It was determined that cotton cultivars had different abilities to tolerate the growth inhibiting effects of the wheat straw in laboratory bioassays and greenhouse pot studies. Ray and Hastings (1992) reported variation of response within species of flax (four cultivars, and two wild related species in the same genus), and barley (four cultivars), to phenolic acids, and wild oat residue extract for the barley cultivars. It was suggested that differences among genotypes in their ability to tolerate adverse alleopathic compounds could be used in breeding programs to develop cultivars that have greater tolerances to allelochemicals produced by weeds, or in the residues of previous crops. However it needs to be shown whether or not allelopathic effects like those observed by Ray and Hastings are of practical significance in a field situation.

Few studies have investigated the differential effect on subsequent crop growth by crop residues from cultivars within the same crop species. In some instances there may as much variation within, as between species in the production of, or response to, plant chemicals (Purvis et al. 1985). Purvis and Jones (1990) conducted experiments comparing the allelopathic effects of stubble residues of 11 sorghum, and 12 sunflower cultivars. Wheat growth was significantly inhibited from residues of all 11 sorghum cultivars and 10 of 12 sunflower cultivars.

Additional research into the possible allelopathic effects of crop residues is needed because of the increased importance of maintaining crop residues on the soil surface in conservation tillage systems (Martin et al. 1990). There is some concern that allelopathic effects from previous crop residues may be more of a concern under MT or DS, compared to CT. Research reported by Windels and Warnes (1996) showed reduced plant stands and crop yields of winter and spring small grain crops in Minnesota under DS compared to MT or CT. Their research was designed to determine whether allelopathic effects or increased fungal disease were the cause of reductions of plant stands or crop yields. Fungal diseases were ruled out and the main effect of decreased growth under DS compared to MT or CT was attributed to allelopathic effects.

A series of experiments were designed to determine if the hypothesis was valid that use of conservation tillage systems, i.e. MT and DS, compared to the use CT will increase the adverse allelopathic effects of residues from cultivars of one crop species on another crop species grown as a subsequent crop. A planned set of laboratory, greenhouse and field experiments were designed and conducted to test the hypothesis. The laboratory experiments were conducted with the objective to determine if there were interactions between different source cultivar residues and the target cultivars as measured by germination percentage and coleoptile and radicle growth. It was planned to use results from the laboratory experiment to select cultivars for use in the greenhouse and field experiments. The greenhouse experiments were conducted with the objectives of measuring the allelopathic effects of the residues on selected cultivars while looking at the factors of growth medium (i.e. topsoil versus washed sand) and location of the residue (i.e. surface application to simulate DS compared to mixing the residues into the growth medium to simulate CT). The field experiments were conducted to determine whether or not the interactions between source residue and tillage systems were observable in a field situation.

3.2 Materials and Methods

3.2.1 Laboratory Germination Experiments

Two experiments were conducted. The first experiment measured the effect of the distilled water control and five canola cultivar residue extracts on the germination of nine barley cultivars. There were 54 petridishes per replicate or block in the first experiment. Each individual block was placed on a separate shelf in the laboratory and light was excluded by covering the front of the wooden shelving units with black plastic. The second experiment measured the effect of the distilled water control and the nine barley cultivar residue extracts on the germination of five canola cultivars. There were 50 petridishes per block in the second experiment and the blocks were placed in similar wooden shelving units as described above. Both experiments were a four replicate factorial, with source cultivar extract as one factor and target cultivar seed as a second factor. A Randomized Complete Block (RCB) statistical analysis was done using a two-way Analysis of Variance (ANOVA) (Cohort 1995). Cultivar extract, and cultivar seed factor means were compared using Student Newman Keuls (SNK) at P=0.05. Selected interactions of experimental factors, of practical significance, were analyzed using an LSD test with Least Square Means (SAS 1989).

Crop residues were collected at harvest from samples of five canola cultivars and nine barley cultivars, grown at the Ellerslie Research Station of the University of Alberta, Edmonton, Alberta. The canola (*Brassica napus*) cultivars used were Alto, Bounty, Hyola 401, Legend, and Westar. The barley (*Hordeum vulgare*) cultivars used were Abee, Bonanza, Condor, Duke, Heartland, Harrington, Leduc, Noble and Virden. The samples were taken form the field plots that were grown in 1990 as part of the field experiments described below. After collection the residues were air dried, coarsely ground through a hammer mill, and then further ground with a Wiley mill to pass a two mm mesh screen and then stored in plastic airtight containers. The residues were samples from the top growth with the grain removed using a threshing machine. .

The residues were extracted using a one to ten ratio of residue to double deionized water (40 g of residue in 400 ml of water), in a 500 ml stoppered erlenmeyer flask. This ratio of residues to water has been used in similar experiments (Nielson et al., 1960; Yakle and Cruse, 1884; Martin et al., 1990). The residue-water mixture was shaken for five minutes, and then let stand for 24 hours in the dark at 20° C. After the 24 hour period the mixture was again shaken briefly, filtered through cheese cloth, and then through a number one Whatman filter paper. The filtered solution was stored in the dark at five degrees C overnight. The extraction was done to remove water soluble compounds that would normally be leached out of residues by precipitation and would be present in the soil and come in contact with germinating seeds and young seedlings.

The seed of the target crop species cultivars were prepared by surface sterilizing the seed for five minutes in five percent sodium hypochlorite, then rinsing three times in distilled water and drying. This was done to remove most seed-born fungal spores that could infect the germinating seeds, damage the germinates, and confound the effects of allelopathic compounds to be observed. Ten seeds of each cultivar were placed on a number one Whatman filter paper (95 mm diameter) in a petridish (100 mm inside diameter, and 15 mm depth), with another filter paper placed over the seeds. Five ml of the appropriate extract solution or the distilled water (control) was added. The petridishes were placed in a loosely sealed plastic bag and then stored in the dark at 20° C for 120 hours. After 120 hours the petridishes were removed from the dark and measurements were taken of the number of seeds out of ten that germinated. A seed was considered to have germinated only if the coleoptile plus radicle length was ten mm or greater. Measurements were also made of the length of the coleoptile and radicle and recorded.

3.2.2 Emergence and Early Growth, Greenhouse Experiments

The crop residues, and two selected cultivar seeds used in the laboratory experiments were used in two sets of greenhouse experiments. The residues used were only coarsely ground and not fine ground as in the laboratory experiments described above. The coarsely ground residues were used rather than the field collected residues to obtain a more homogeneous mixture of residue. This was to avoid pieces of straw potentially making up a larger than actual portion of the residue sample applied to an individual greenhouse container and therefore not enough of the chaff. Both sets of experiments were four replicate factorials with three factors, repeated in both topsoil and washed sand.

In the first set of two separate but related experiments the factors were canola cultivar residues (six; a distilled water control plus the five canola cultivar residues as in the laboratory experiment), barley cultivar seeds (two; one of the least affected, and one of the most affected as determined by measurements in the laboratory germination experiment described above), and canola residue location (two; mixed into the growth medium to simulate CT, and spread on the growth medium surface to simulate DS). A RCB design was used with four replicates. Statistical analysis was done using a three-way ANOVA. Canola cultivar residue, barley cultivar seed source, and canola residue location factor means were compared using SNK at P=0.05, unless otherwise noted.

In the second set of two separate but related experiments the factors were barley cultivar residues (ten; a distilled water control plus the nine barley cultivar residues as in the laboratory experiment), canola cultivar seeds (two; the least affected, and one of the most affected as determined by measurements in the laboratory germination experiment), and barley residue location (two; mixed into the growth medium to simulate CT, and spread on the surface of the growth medium to simulate DS). A RCB design was used with four replicates. Statistical analysis was done using a three-way ANOVA. Barley cultivar residue, canola cultivar seed source, and barley residue location factor means were compared using SNK at P=0.05.

The plastic containers used in the experiments were 600 ml in volume and were 110 mm inside diameter. 500 ml of the appropriate growth medium type was added along with a balanced fertilizer blend at an equivalent of 100 kg ha^{-1} N, 50 kg ha^{-1} P2O5, 50 kg ha^{-1} K2O, 18 kg ha^{-1} S, 40 kg ha^{-1} ground calcitic limestone and 0.1 g/container of fritted trace elements. The plant nutrients especially nitrogen were added to reduce the effect of immobilization of nutrients especially nitrogen when the added residues are metabolized by soil microbes. Immobilization of nutrients as a result of adding residues has been shown to have a greater adverse effect than allelopathic compounds from previous crop residues under certain conditions (Kalburtji and Mosjidis 1993). The amount of barley residue added was 5.0 g, and was equivalent to the amount of residue from a 5.0 t ha^{-1} crop of barley using a harvest index of 0.50 The amount of canola residue added was 5.7 g, and was equivalent to the amount of residue from a canola crop yielding 2.7 t ha^{-1} using a harvest index of 0.32. The amount of residue added to the containers could greatly affect the type of allelopathic effect observed. The greater the amount of residue present the greater the concentration of potential allelopathic compounds that can be introduced into the soil solution and act upon the subsequent crop. Purvis et al. (1985) reported that at a lower concentration (six g wheat straw/l) wild oat germination was stimulated relative to a distilled water control, while at a higher concentration (25 g wheat straw/l) the germination was inhibited. The containers used to simulate CT had the residues added and mixed into the soil before seeding six seeds of the appropriate cultivar into the soil. The containers used to simulate DS had the residues spread evenly over the soil surface after seeding. The containers were hand watered every couple of days as needed so the plants had adequate moisture. Any excess water was allowed to drain through three two mm holes drilled in the bottom of the containers, but little if any leaching out of the containers was observed.

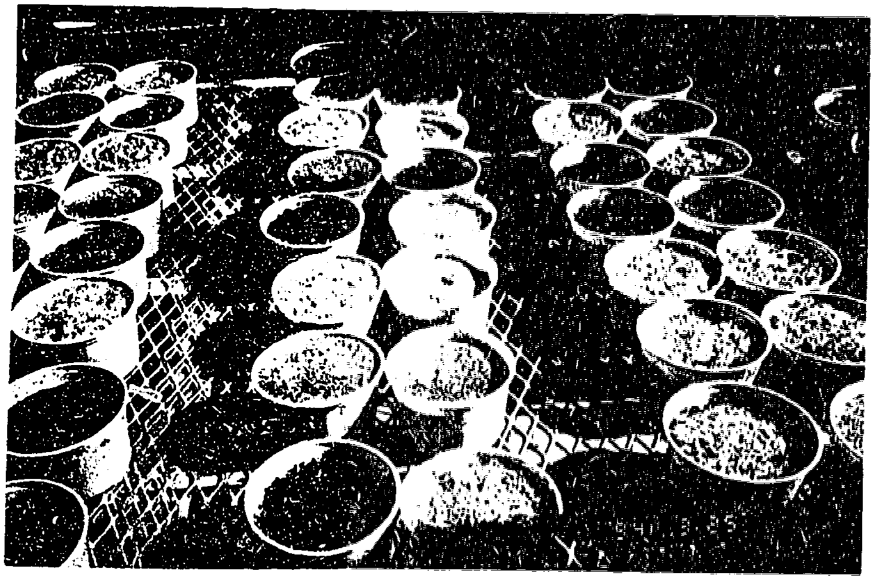

Figure 3.1. Containers in the greenhouse, after seeding. Various residue treatments are visible.

Figure 3.2. Barley seedlings in the greenhouse at the time of emergence counts.

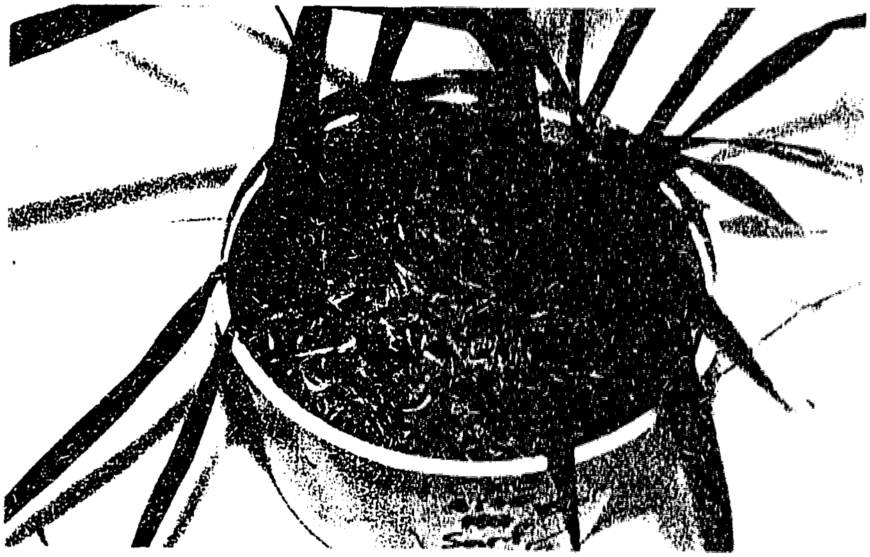

Figure 3.3. Bonanza Barley growing in topsoil with Alto Canola residue applied to the soil surface to simulate direct seeding.

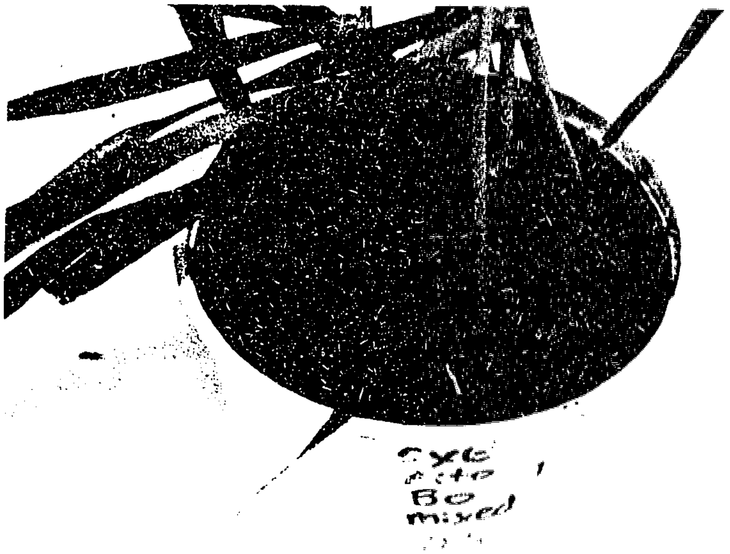

Figure 3.4. Bonanza Barley growing in topsoil with Alto Canola residue mixed into the soil to simulate conventional tillage.

The seeded containers were placed in the greenhouse and watered on day zero, March 22, 1994. The greenhouse was maintained at 20° C, with light at an average of 400 micro Einstein $m^{-2} s^{-1}$ and dark periods of 18 and 6 hours respectively. Emergence counts were taken one week after seeding. Video images of the plants in each individual container were taken at weeks one, two, three, four and five using an eight mm videocamera. The two-dimensional images were used to estimate the amount of top-growth in cm^2 by using image analysis (Decagon 1994). This allowed an estimation of growth at each of the five times noted above without the need to destructively sample the plants until week five. The distance the video camera was from the plants varied at each taping depending on the size of the plants, and was adjusted to allow the plants to be as large as possible within the picture frame of the video camera. Each individual image was calibrated before estimation of the area by noting the outside diameter of the containers as 11.43 cm. The images of the plants were separated from the rest of the video image by selection of an appropriate range of gray scale values. The plants were darker than the white plastic containers or the white cardboard background yet lighter than lettering on the containers, or soil showing above the edge of the containers. Images were always taken during the hours of 1:00 to 3:00 p.m. After the last image was recorded with the video camera at week five, the plants were cut off at the soil surface and the top growth was dried at 80° C for two days in paper bags and then weighed.

3.2.3 Field Experiments

Two site years of the experiment with five canola cultivar residues affecting the yield of two barley cultivars, and two site-years of the experiment with nine barley cultivar residues affecting two canola cultivars were conducted. The cultivars were the same as in the greenhouse experiments above. A Split-Split-Plot factorial design with four replicates was used. The cultivar residue blocks grown were the main plot treatments and were 15 m by six m in size. The cultivars were grown the previous year, using minimum tillage. In the second year the main plots were split into three, five m wide by six m long split-plots by randomly applying the three tillage systems CT, MT and DS, and further split, into split-split-plots three m wide by five m long , seeding each half of the split-plot with one of two subsequent crop cultivars.

The canola cultivar residues affecting barley yield experiment was conducted at Three Hills, Alberta , and Ellerslie Research Station, University of Alberta , with seeding and harvest of the canola in 1991 and seeding and harvest of the barley in 1992. The barley cultivar residues affecting canola yield experiment was conducted at the Ellerslie Research Station, University of Alberta, in the years 1991 and 1992, and 1992 and 1993, with seeding, using minimum tillage, of the residue source species the year before seeding the subsequent target crop. The crops were seeded the first or second week in May each year, and harvested at maturity in early September of each year. Yield samples were taken randomly within each plot with no sample taken within one m of the edge of each Split-Split-Plot to avoid any edge effects. Each site-year was analyzed as a separate experiment using ANOVA, and factor treatment means were compared using SNK at P=0.05. Selected interactions of experimental factors were analyzed using an LSD test with Least Square Means (SAS 1989).

Figure 3.5. Direct Seeded Canola In The Presence Of The Previous Years' Barley Residue.

3.3 Results and Discussion

3.3.1 Cultivar Residues Affecting Germination

In the laboratory there were differences among barley cultivars in their ability to tolerate the extracts from residues of canola cultivars. The cultivar Bonanza was one of the most tolerant cultivars, while Virden was one of the least tolerant when compared to all the other barley cultivars (Table 3.1). It is important to not only compare the measurements among the cultivars but to also take into consideration how viable the seed from each individual cultivar is. For example, Bonanza barley was consistently one of the best performing cultivars among the nine barley cultivars for germination percentage, (82%), length of coleoptile, (37mm), and radicle length, (45mm). Additionally when these values where expressed as canola residue treated Bonanza barley as a percentage of distilled water treated Bonanza barley the percentages were respectively 88%, 80%, and 110%, for the three measurements. In contrast Virden had lower values of 26%, 21mm, and 34mm for germination percentage, coleoptile length and radicle length and the percentages of the canola residue treated measurements of the distilled water treated measurements were 47%. 53% and 69% respectively. The Virden barley was greatly affected by the canola residue extracts, and Bonanza much less. In contrast the cultivar Duke had the lowest values for germination percentage, coleoptile length and radicle length, respectively 21%, 17mm and 22mm but the percentages of the canola residue treated measurements of the distilled water treated measurements were 91%, 76% and 58% respectively. Duke barley seed was less viable compared to other barley cultivars, however for those seeds that did germinate and develop coleoptiles the canola residue extracts had less effects than for Virden barley. There was no observed interaction among canola residues and barley cultivars for germination, but interaction was noted for both coleoptile length and radicle length.

Table 3.1. Barley cultivar germination, coleoptile length, and radicle length as affected by canola residues, in the laboratory 1992.

Barley Cultivar	Germination (G.) Percentage	G. % of Control	Coleoptile Length (C.L.) mm	C.L. % of Control	Radicle Length (R.L.) mm	R.L. % of Control
Abee	75 ab	79% ab	24 bc	56 b	29 c	42 c
Bonanza	82 a	88a	37 a	80 a	45 a	110 a
Condor	54 c	69 ab	28 b	51 b	30 c	42 c
Duke	21 e	91 a	16 d	76 a	22 d	58 b
Harrington	33 d	57 ab	28 b	61 b	36 a	43 c
Heartland	54 c	64 ab	28 b	61 b	46 a	65 b
Leduc	70 b	78 ab	33 a	75 a	38 b	68 b
Noble	64 b	71 ab	35 a	73 a	40 ab	60 b
Virden	26 de	47 c	21 c	53 b	34 bc	69 b
Cultivar by Residue Interaction	ns	ns	*	*	*	*
Coefficient of Variance	24%	35%	22%	28%	22%	25%

Different letters within columns indicate difference at P= 0.05. * significant at P= 0.05.

There were differences among canola residues as far as the reduction in barley germination, coleoptile length, and radicle length compared to the distilled water control (Table 3.2). The Legend residue reduced germination the most, although not significantly more than Hyola 401. The overall effect of canola cultivar residues on coleoptile and radicle growth was similar, with Hyola 401 tending to restrict barley growth the most amongst the canola cultivar residues.

Table 3.2. The effect of canola cultivar residues on the germination, coleoptile length , and radicle length of barley, in the laboratory 1992.

Canola Residue	% Germination	Coleoptile Length mm	Radicle Length mm
Control	73 a	43.1 a	60.6 a
Alto	58 b	28.9 bc	35.9 b
Bounty	58 b	37.1 ba	37.0 b
Hyola 401	51 bc	26.4 c	32.1 b
Legend	49 c	29.0 bc	36.5 b
Westar	57 b	29.0 bc	35.8 b

Different letters within columns indicate difference at P=0.05.

For the control, which consisted of distilled water with no canola residues, the cultivars Condor and Noble developed the longest coleoptile compared to the other barley cultivars (Table 3.3). However when Condor was treated with the extracts from the canola residues it was one of the most adversely affected barley cultivars with shortened coleoptile length compared to the other barleys. The exception was for the Hyola 401 residue that did not affect it as much relative to the other barleys. Harrington was similar in response to Condor but seemed somewhat more variable in response. Bonanza reacted quite differently, seeming better able to tolerate the canola residues.

Table 3.3. Coleoptile lengths (mm) for the nine barley cultivars as affected by the control and five canola cultivar residues.

Barley Cultivars	Control	Alto	Bounty	Hyola 401	Legend	Westar
Abee	43.3 bc	22.5 cd	30.0 c	21.8 b	18.5 c	28.5 cde
Bonanza	46.0 bc	36.3 a	40.5 ab	32.5 a	39.5 ab	38.5 a
Condor	54.8 a	31.8 abc	24.3 de	30.5 a	29.0 cd	23.0 d
Duke	20.5 d	15.5 d	17.5 e	20.0 b	16.3 c	11.3 f
Harrington	46.3 bc	27.5 bcd	30.5 cd	20.8 b	33.8 abc	29.3 bcd
Heartland	45.8 bc	35.5 ab	41.0 ab	31.0 a	40.5 a	34.5 abc
Leduc	43.8 bc	34.3 ab	33.8 bc	33.3 a	29.5 cd	36.5 ab
Noble	47.8 abc	35.0 ab	42.0 a	30.0 a	32.5 bc	37.3 a
Virden	39.5 c	22.0 cd	24.3 de	17.5 b	21.3 de	21.3 e

Different letters within a column or canola residue type indicate a difference among barley cultivars at P=0.05.

For radicle length, the trends were similar in that Hyola 401 was the most adverse canola residue and Bounty the least adverse canola residue (Table 3.4). Bonanza had one of the shortest radicle lengths under control conditions, and yet one of the longest compared to the other barley cultivars when subjected to the canola residue extracts. Harrington varied from long radicle lengths under the control to short for some canola residues and moderate for others.

Table 3.4. Radicle lengths (mm) for the nine barley cultivars as affected by the control and five canola cultivar residues.

Barley Cultivars	Control	Alto	Bounty	Hyola 401	Legend	Westar
Abee	69.3 b	31.3 c	31.3 d	25.5 b	27.3 c	31.3 d
Bonanza	41.0 d	48.0 a	46.8 ab	37.8 a	45.5 a	44.3 ab
Condor	71.0 b	32.3 c	25.0 c	30.5 ab	32.5 bc	28.0 d
Duke	37.5 d	21.3 c	26.3 c	26.3 b	25.0 c	13.0 c
Harrington	83.8 a	32.5 c	37.5 bc	26.3 b	38.8 a	42.5 ab
Heartland	71.3 b	43.8 ab	48.8 a	38.8 a	46.3 a	50.5 a
Leduc	56.3 c	38.8 ab	38.0 bcd	34.5 ab	38.3 ab	38.8 bc
Noble	66.8 b	38.8 ab	43.3 abc	35.5 ab	40.0 a	42.5 abc
Virden	48.8 c	36.3 bc	36.3 cd	33.5 ab	35.0 b	31.3 d

Different letters within a column or canola cultivar residue indicate a difference among barley cultivars at P=0.05.

The barley cultivars exhibited shorter radicle lengths for all canola residues when compared to the control (Table 3.2). Residue from Hyola 401 tended to be the most harsh among the canola residues on the barley cultivars with only small differences among the various barley cultivars. Bounty residue was less harsh on the barley cultivars with a larger difference between the least affected Heartland barley and the most affected Condor barley..

In the related reciprocal experiment, that studied the effects of barley cultivar residues on the germination and growth of canola, there were differences observed among the various canola cultivars (Table 3.5). Alto was the least adversely affected, Legend intermediately affected, and Westar was one of the most adversely affected as measured by germination, coleoptile growth, and radicle length.

Table 3.5. Canola cultivar germination, coleoptile length, and radicle length, as affected by barley cultivar residues, in the laboratory 1992.

Canola Cultivar	Germination (G.) Percentage	G. % of Control	Coleoptile Length (C.L.) mm	C.L. % of Control	Radicle Length (R.L.) mm	R.L. % of Control
Alto	51 a	61 a	6 a	53 a	6 a	82 a
Bounty	11 c	16 cd	2 bc	20 b	2 c	15 b
Hyola 401	8 c	9 d	1 c	7 c	1 c	6 b
Legend	35 b	36 b	3 b	24 b	3 b	20 b
Westar	8 c	19 c	1 c	26 c	1 c	25 b
Cultivar by Residue Interaction	ns	ns	*	*	*	*
Coefficient of Variance	23%	27%	22%	26%	22%	28%

Different letters within columns indicate difference at P= 0.05. * significant at P= 0.05.

There were differences among the different barley cultivar residues as they affected the germination and growth of the canola (Table 3.6). All of the barley cultivar residues reduced germination, coleoptile and radicle growth relative to the distilled water control. The only minor difference observed was that the residue from Virden barley had less of an adverse effect on germination of the five canola cultivars than Abee, Bonanza, Harrington, and Condor cultivar residues. Interactions were observed among canola cultivars and barley residues for the three measurements of germination, coleoptile length, and radicle length. Hyola 401 had the second highest germination at 92.5% for the control treatment of distilled water, but when treated with barley residue extracts, it had some of the lowest germination percentages (Table 3.7). Alto was intermediate for germination under the control treatment but was consistently the least adversely affected cultivar when subjected to the nine barley cultivar residues.

Table 3.6. Effect of barley cultivar residues on canola germination and growth.

Barley Cultivar Residue	Germination (%)	Coleoptile Growth (mm)	Radicle Growth (mm)
Control	79 a	12 a	14 a
Abee	21 c	3 b	2 b
Bonanza	20 c	3 b	3 b
Condor	15 c	2 b	2 b
Duke	27 bc	3 b	3 b
Harrington	19 c	3 b	2 b
Heartland	25 bc	3 b	3 b
Leduc	22 bc	2 b	2 b
Noble	24 bc	2 b	2 b
Virden	33 b	4 b	4 b

Different letters within columns indicate a difference at 0.05.

Table 3.7. Germination (%) for the five canola cultivars as affected by the control and the nine barley cultivar residues.

Barley Cultivar Residues	Canola Cultivars				
	Alto	Bounty	Hyola 401	Legend	Westar
Control	85.0 ab	72.5 b	92.5 a	97.5 a	47.5 c
Abee	45.0 a	5.0 b	2.5 b	42.5 a	10.0 b
Bonanza	40.0 a	15.0 b	2.5 b	35.0 a	5.0 b
Condor	45.0 a	5.0 c	0.0 c	22.5 b	2.5 c
Duke	57.5 a	10.0 b	12.5 b	47.5 a	5.0 b
Harrington	50.0 a	5.0 c	2.5 c	30.0 b	5.0 c
Heartland	57.5 a	7.5 c	20.0 bc	27.5 b	10.0 c
Leduc	40.0 a	17.5 b	5.0 b	35.0 a	12.5 b
Noble	50.0 a	17.5 bc	10.0 c	30.0 b	10.0 c
Virden	70.0 a	20.0 c	17.5 c	45.0 b	12.5 c

Different letters within a row or barley residue indicate a difference among canola cultivars at P= 0.05.

Coleoptile length measurements resulted in similar relationships among canola cultivars and barley residues (Table 3.8). Hyola exhibited the longest coleoptile growth under the control treatment, but had the shortest coleoptile lengths when treated with many of the barley residues. Alto had one of the shortest coleoptile lengths under the control treatment but had one of the longest when treated with the barley cultivar residues. Bounty appeared to react somewhat differently to various barley residues when compared to the other canola cultivars. It had the shortest coleoptile length under the control treatment and remained short when compared to the other canola cultivars for the barley residues Abee, Heartland, Leduc, and Virden. However it had the longest coleoptile length when treated with the barley residues of Bonanza and Noble, second longest for Duke residues, and intermediate for Condor and Harrington residues.

Table 3.8. Coleoptile growth (mm) for the five canola cultivars as affected by the control and nine barley cultivar residues.

Barley Cultivar Residues	Canola Cultivars				
	Alto	Bounty	Hyola 401	Legend	Westar
Control	12.0 b	9.8 c	20.0 a	13.0 b	3.8 d
Abee	7.8 a	0.5 b	0.5 b	2.8 b	1.3 b
Bonanza	3.8 ab	5.0 a	1.0 b	2.5 ab	1.3 b
Condor	5.8 a	1.0 b	0.0 c	3.0 b	0.3 c
Duke	8.8 a	2.3 b	1.0 b	2.3 b	0.8 b
Harrington	9.0 a	1.0 b	0.5 b	2.0 b	0.5 b
Heartland	7.3 a	1.3 c	3.0 bc	4.3 b	1.3 c
Leduc	3.5 a	1.5 ab	2.5 ab	3.3 a	0.5 b
Noble	2.8 ab	3.5 a	1.0 ab	2.0 ab	0.8 b
Virden	6.0 a	2.0 bc	3.3 bc	5.0 ab	1.5 c

Different letters within a row or barley residue indicate a difference at P=0.05.

For radicle length, the relationships among canola cultivars and barley residues were similar to the germination and coleoptile measurements (Table 3.9). Again, Alto had one of the shorter radicle lengths compared to the other canola cultivars when treated with distilled water for the control treatment. For the barley residues it had one of the longest radicle lengths. As for the other measurements, Hyola 401 responded with the most amount of radicle growth under the control treatment but had some of the lowest radicle lengths for many of the barley residues.

The radicle growth for Bounty varied similarly as coleoptile growth. Bounty reacted somewhat differently than the other canola cultivars to the barley residues. It had radicle growth that varied for the control and barley residues, when compared to the other canola cultivars.

Table 3.9. Radicle growth (mm) for five canola cultivars as affected by the control treatment, and the nine barley cultivar residues.

Barley	Canola Cultivars				
Residues	Alto	Bounty	Hyola 401	Legend	Virden
Control	11.8 c	12.3 c	25.0 a	14.8 b	3.8 d
Abee	5.3 a	0.5 c	0.5 c	3.0 ab	1.3 bc
Bonanza	4.5 a	3.8 ab	0.5 c	2.8 abc	1.3 c
Condor	4.0 a	1.0 bcd	0.0 d	2.8 ab	0.3 cd
Duke	9.3 a	1.8 b	1.0 b	2.8 b	0.8 b
Harrington	7.5 a	1.0 b	0.3 b	2.0 b	0.3 b
Heartland	7.0 a	1.3 c	3.3 bc	3.8 b	1.3 c
Leduc	3.8 a	1.5 ab	2.5 ab	2.8 ab	0.5 b
Noble	2.8 ab	3.3 a	1.0 ab	2.0 ab	0.8 b
Virden	6.5 a	2.0 bc	3.5 bc	4.3 ab	1.3 c

Different letters within a row or residue type indicate a difference at P=0.05.

The laboratory experiments that were designed to determine whether or not there were observable and different allelopathic effects among source cultivar residues and target cultivars, confirmed the existence of these effects. There were differences in the adverse allelopathic effects among both the canola cultivar residues and the barley cultivar residues. There were also differences in the tolerance levels among the cultivars of canola and barley. As well there were observable interactions between source cultivar residues and target cultivars.

3.3.2 Cultivar Residues Affecting Subsequent Crop Growth in the Greenhouse

As a follow-up to the initial experiments in the laboratory the set of experiments conducted in the greenhouse did show some differences among residue management methods or placement , the soil type, and in some instances subsequent crop cultivars, and cultivar residues. However, there were no interactions observed between the various factors.

The effect of the five canola cultivar residues on the growth of two selected barley cultivars was more noticeable in washed sand having no organic matter, than in topsoil with 7.7% organic matter. Crop emergence of the barley cultivars grown in the sand with the canola residues present, was significantly less for both barley cultivars compared to when the two barley cultivars were grown in the control that consisted of sand with no canola residues present. However in the topsoil the canola residues had no noticeable effect compared to the control treatment with no canola residue present (Table 3.10).

Table 3.10. The effect of canola residues on the emergence of two barley cultivars as affected by growth media.

Residue Treatment	Bonanza Barley Emergence (%)	Harrington Barley Emergence (%)	Coefficient of Variation (%)
Sand, no canola residue	92 a	79 a	10.5
Sand, average of 5 canola residues	62 b	55 b	49.9
Soil, no canola residue	96 a	83 a	14.4
Soil, average of 5 canola residues	85 a	72 a	31.7

Different letters within columns and growth medium type, show significant difference at P=0.05.

The allelopathic effects of the canola residues on barley emergence were much more pronounced in the coarse textured (Loamy-sand) sand that had no organic matter present, compared to the high organic matter (7.7%) fine textured (loam) topsoil (Table 3.11). The sand showed no differences for the growth factors of canola residue type, barley cultivar, and residue placement when crop emergence was measured. However all growth measurement estimates using image analysis at weeks one, two, three, four and five, and dry matter weight at week five showed that the surface applied residues restricted growth less than when the residues were mixed into the sand. There were no observable differences among the barley cultivars or canola residue type when grown in the sand. All the seeds germinated similarly whether the residues were mixed in the growth medium, but growth was reduced when mixing the residues in compared to leaving the residues on the surface. The allelopathic effects of the canola residues was so pronounced the barley cultivars were so adversely affected in the sand by the various canola residues that small differences amongst barley cultivars and canola residues were not detectable. When the barley was grown in the soil, there were no observable effects attributable to canola residue location (Table 3.11). However there was a difference among barley cultivars observed at emergence. The cultivar Bonanza had an average of 85.4% emergence compared to Harrington that had only 71.7% emergence. The LSD was 11.2% at P=0.05. The control emergence levels were 95.8% and 83.3% for Bonanza and Harrington respectively. The presence of canola residues caused a 10.9 % reduction in emergence for Bonanza and a 13.9% reduction in emergence for Harrington. The more favorable growing conditions in the soil compared to the sand allowed small differences in emergence between the two barley cultivars to be observed.

The characteristics of the topsoil that make it more favourable for crop growth include such factors as greater cation exchange capacity, moisture retention and availability. The finer textured loam soil has a greater cation exchange capacity so that plant nutrient cations can be stored and released for crop use more effectively compared to the sand that has a low cation exchange capacity. In a similar way the finer textured soil compared to the coarse textured sand, can store more moisture for the same volume of growth medium and release the plant available moisture over a longer period, thus reducing the time the plants can be subjected to a moisture deficit.

Table 3.11. The effect of canola residue placement on the growth of barley in sand or topsoil.

Canola Residue Location and Growth Media	Week 1 Image Area cm^2	Week 2 Image Area cm^2	Week 3 Image Area cm^2	Week 4 Image Area cm^2	Week 5 Image Area cm^2	Week 5 Dry Matter Weight g
Sand Surface	15.8 a	48.8 a	127.9 b	178.0 b	255.3 b	2.1 b
Sand Mixed	8.9 b	24.5 b	64.7 c	102.3 c	162.7 c	1.5 c
Sand Control	19.1 a	60.7 a	161.5 a	231.6 a	382.1 a	3.2 a
Coefficient of Variation (%)	95	69	65	62	56	51
Soil Surface	24.2 a	73.6 a	204.5 a	261.8 a	388.7 a	3.4 a
Soil Mixed	23.4 a	76.2 a	219.5 a	274.3 a	421.7 a	3.7 a
Soil Control	17.3 a	78.9 a	190.7 a	236.7 a	376.8 a	4.0 a
Coefficient of Variation (%)	48	35	33	28	31	30

Different letters within columns . and growth media type indicate a difference at P=0.05.

The organic matter and clay colloids in the topsoil were more capable of adsorbing the adverse allelopathic compounds, probably phenolic and other organic acids originating and leached from the canola residues. In the sand there was little adsorption of the allelopathic compounds and the relative concentration of the compounds was greater in the soil solution in the sand compared to the soil solution in the topsoil. The small differences between barley cultivar tolerance to adverse allelopathic compounds were more easily observed in the topsoil as indicated. There was an effect of canola residue type at weeks three through five, for the barley grown in the topsoil as measured using image analysis (Table 3.12).

Table 3.12. The significance of canola residue type effect on the average barley growth as measured by image analysis, weeks one through five.

Time from Planting	Week 1	Week 2	Week 3	Week 4	Week 5
Probability of Significance	P=0.2	P=0.66	P=0.05	P=0.03	P=0.09

At weeks three through five Legend residues caused less adverse allelopathic effect compared to Bounty residues (Table 3.13). The other three canola cultivar residue types were intermediate in effect among Legend and Bounty.

Table 3.13. The effect of canola residue type on barley growth.

Canola Residue Type	Barley Growth Image Analysis cm^2, Week 3	Barley Growth Image Analysis cm^2, Week 4	Barley Growth Image Analysis cm^2, Week 5
Alto	207.7 ab	260.1 ab	390.2 ab
Bounty	171.9 b	218.3 b	339.3 b
Hyola 401	211.9 ab	288.7 ab	415.9 ab
Legend	250.8 a	302.4 a	466.3 a
Westar	217.6 ab	270.8 ab	414.3 ab

Different letters within columns show significant difference at P=0.05.

The effect of the barley residues on canola growth was more pronounced and there were significant effects of residue location in both the sand and the topsoil (Table 3.14). As in the previous experiment leaving the residues on the surface had less adverse effect on the crop growth than when the residues were mixed into the growing medium. The effects of the residues were again less adverse in the topsoil than in the sand.

Table 3.14. The effect of barley cultivar residues on canola emergence in the greenhouse.

Barley Residue Location and Growth Media	Canola Emergence %
Sand Surface	54.4 b
Sand Mixed	40.7 c
Sand Control	70.8 a
Soil Surface	81.0 a
Soil Mixed	66.6 b
Soil Control	79.2 a

Different letters within columns , and growth media type show significant difference at P=0.05. Coefficient of Variation was 48% for the sand treatments and 26.4% for the soil treatments.

There were canola cultivar differences observed in both the sand and the topsoil. Alto had an average emergence of 65% and 86% for the sand and topsoil respectively, while Westar had values of 30% and 61% respectively. The measurements of canola growth at weeks one through five show that the canola grew better in the topsoil compared to the sand (Table 3.15). This is a reflection of the value of topsoil that is enriched with organic matter as a growth medium compared to the loamy sand that could represent a severely eroded soil that has little or no organic matter enrichment. Even if plant nutrients are added as fertilizer, as in this experiment, it is difficult to achieve as good as growth in a eroded low organic matter soil compared to a non-eroded soil in the same field. The effects of barley residues were similar in effect but not the relative amount up to week three when comparing the growth in sand to growth in the topsoil. The similarity was that there were significant effects of the location of barley residues and differences between the two canola cultivars up to week three. In both growth media there was no significant difference among barley residue types in weeks four and five. At weeks four and five there were differences observed among barley residue location and canola cultivar for the image analysis growth measurements in the sand. However in the soil for the same time periods significant differences were observed for barley residue location only.

Table 3.15. Barley residue affecting canola cultivar growth in two different growth media, two locations of residue, and two different canola cultivars.

Growth Medium	Canola Cultivar	Barley Residue Location	Week 1 cm^2	Week 2 cm^2	Week 3 cm^2	Week 4 cm^2	Week 5 cm^2	Dry Matter Week 5
Sand	Alto	------------	0.7 a	6.2 a	19.5 a	52.0 a	85.7 a	1.1 a
	Westar	------------	0.4 b	3.1 b	11.0 b	31.2 b	56.6 b	0.8 b
Soil	Alto	------------	1.8 a	28.8 a	110.8 a	162.7 a	265.3 a	3.5 a
	Westar	------------	1.0 b	21.0 b	93.5 b	152.6 a	259.0 a	3.3 a
Sand	----------	Surface	0.8 a	8.1 a	24.1 a	61.2 a	105.8 a	1.6 a
	----------	Mixed	0.3 b	1.2 b	6.4 b	21.9 b	36.5 b	0.4 b
Soil	----------	Surface	2.0 a	33.4 a	123.6 a	172.0 a	275.9 a	3.7 a
	----------	Mixed	0.8 b	16.3 b	80.7 b	143.3 b	248.4 b	3.0 b

Different letters denote a significant difference at 0.05, among any two combinations of cultivars or residue placement within a soil type, at any time period.

These results are similar to results by Morris and Parrish (1992), who also observed that incorporation of sunflower (*Helianthus annus*) residues, simulating CT, caused greater inhibition of wheat (*Triticum aestivum*) development compared to surface applied residues, simulating DS culture. Purvis and Jones (1990) also reported increased inhibition when crop residues were incorporated rather than left on the soil surface. This is perhaps that the effective concentration of adverse allelopathic compounds is greater when mixed into the seedbed, rather than left on the soil surface.

In similar field studies conducted with two cotton cultivars , the more tolerant "Paymaster 404" and the least tolerant "Acal A246", as determined in the laboratory and greenhouse bioassays, exhibited major reductions in growth only when wheat residues were present in the seedbed. If the residues were left on the surface, or mixed well into the plow layer there was little effect on the cotton germination, emergence, and seedling growth. It would appear that DS or CT was more favorable than MT, as far as any allelopathic effect of the wheat residues on subsequent cotton growth (Hicks et al. 1989).

3.3.3 Cultivar Residues Affecting Subsequent Crop Growth in the Field

Both field experiments, Three Hills 1992 site, and the Ellerslie 1992 site, where the effect of five canola cultivar residues on the growth of two barley cultivars was investigated showed a difference among tillage systems ((Table 3.16). However at the Three Hills site, DS resulted in lower total weight, grain yield, and straw yield compared to MT and CT. In contrast at Ellerslie DS resulted in higher yield measurements as noted above, than MT and CT. There are a number of factors that can cause a difference among tillage systems at any one site in an individual year. One is the moisture conditions after seedbed preparation and seeding. For example if the soils tend to be moist at this time but there is no rainfall received for a long period (eg. One month) after seeding the CT seedbed will tend to dry out more to the depth of tillage (normally 100 to 150 mm), but the residues on the soil surface for a DS seedbed will conserve moisture relative to CT and early crop emergence and growth will be greater. Another factor is the overall moisture availability after seeding and throughout the growing season. If there is a moisture surplus the moisture conserving characteristics of DS relative to MT or CT is of no advantage and can in fact result in increased water logging of the root zone, as well as cooler seedbed temperature, both of these effects can result it decreased growth for DS compared to MT or CT. In the same experiments conducted at Three Hills and Ellerslie these types of factors could have caused the relative differences between tillage systems. It is alse important to note that the differences among DS and, MT and CT were not large even though statistically significant.

Table 3.16. The effect of tillage systems on the growth of barley with five different canola cultivar residues present.

Site	Yield Measurement t ha^{-1}, except for the Harvest Index that is a ratio	CT	MT	DS	Coefficient of Variation (%)
Three Hills 1992	Total Weight	9.6 a	9.1 a	8.4 b	19.8
	Grain Yield	4.6 a	4.5 a	4.2 b	20.5
	Straw Yield	4.9 a	4.6 a	4.2 b	20.6
	Harvest Index	0.48 a	0.49 a	0.50 a	5.7
Ellerslie 1992	Total weight	10.4 b	10.1 b	11.2 a	16.0
	Grain Yield	5.6 b	5.4 b	6.3 a	19.8
	Straw Yield	4.8 b	4.7 b	5.5 a	15.7
	Harvest Index	0.53a	0.54 a	0.56 a	5.1

Different letters among tillage systems within each site and within each yield measurement indicates a difference at P=0.05.

At Three Hills there were significant differences observed among canola cultivar residues (Table 3.17) and an interaction between these residues and the tillage systems (Table 3.18). The residue from Alto restricted growth more than the other cultivars for the yield measurements of total weight, grain yield and straw yield, and Westar tended to have the least adverse effect on growth. The interactions observed between the canola cultivar residues and the tillage system show that the five different canola residues can affect the subsequent growth of the barley differently by using different tillage systems. For total weight, there was no difference among tillage systems for the canola cultivar residues Hyola 401 and Westar. For the residues of Alto and Bounty, CT resulted in greater yield than MT or DS. For the residue of Legend, both CT and MT resulted in higher yields than DS. The interactions between canola cultivar residues and tillage systems were similar for grain weight and straw weight. There was no interaction observed between canola cultivar residues and tillage systems for harvest index.

Table 3.17. The effect of canola cultivar residues on the subsequent barley yield, Three Hills 1992.

Canola Cultivar Residue	Total Weight t ha^{-1}	Grain Yield t ha^{-1}	Straw Yield t ha^{-1}	Harvest Index
Alto	7.8 b	3.8 b	4.0 b	0.49 a
Bounty	9.0 a	4.5 a	4.5 ab	0.51 a
Hyola 401	9.4 a	4.6 a	4.7 a	0.48 a
Legend	9.1 a	4.5 a	4.6 ab	0.50 a
Westar	9.9 a	4.9 a	5.0 a	0.49 a

Different letters among canola cultivar residues within a yield measurement indicate a difference at P=0.05.

Table 3.18. The effect of canola cultivar residues on barley growth as affected by tillage systems, Three Hills 1992.

Canola Cultivar Residue	Total Weight			Grain Yield			Straw Yield		
	CT	MT	DS	CT	MT	DS	CT	MT	DS
Alto	8.9 a	7.3 b	7.3 b	4.3 a	3.5 b	3.5 b	4.6 a	3.8 b	3.7 b
Bounty	9.9 a*	8.6 b	8.6 b	4.8 a *	4.3 ab	4.2 b	5.0 a	4.3 b	4.4 b
Hyola	9.7 a	9.7 a	8.7 a	4.7 a	4.8 a	4.4 a	5.0 a	4.8 a	4.3 a
Legend	10.1 a	10.1 a	7.2 b	4.8 a	4.9 a	3.6 b	5.2 a	5.1 a	3.5 b
Westar	9.3 a	10.1 a	10.2 a	4.5 a	5.0 a	5.1 a	4.7 a	5.1 a	5.2 a

Different letters denote indicate a difference among tillage systems within a canola cultivar residue for each yield measurement at P=0.05. or * P=0.10.

At the Ellerslie site in 1992 there were no differences observed among canola cultivar residue and no interaction between tillage system and canola cultivar residue type. There was however a significant difference observed between the two barley cultivars. Harrington out yielded Bonanza for total weight, grain yield, and straw yield (Table 3.19). There was no significant difference observed for harvest index between the two cultivars.

Table 3.19. Barley cultivar yield measurements, Ellerslie 1992.

Barley Cultivar	Total Weight t ha^{-1}	Grain Weight t ha^{-1}	Straw Weight t ha^{-1}	Harvest Index
Bonanza	10.1 b	5.6 b	4.6 b	0.55 a
Harrington	11.5 a	6.0 a	5.5 a	0.52 a

Different letters among cultivars within a harvest measurement denote a significant difference at P=0.05.

The effect of the nine different barley cultivar residues on the growth and yield of the subsequent canola cultivars was similar at the Ellerslie site in 1992 and 1993 (Table 3.20). In both site-years there was a significant difference among tillage systems. DS resulted in higher yields in both site-years. while MT was lowest in 1992 , and CT lowest in 1993.

There was no significant difference between the two canola cultivars grown as the subsequent crop. However in both site-years there were some differences among the barley cultivar residues (Table 3.21). In 1992 at the Ellerslie site the barley residue from Condor barley had the least adverse effect on the growth of canola, as measured by yield measurements. The two barley cultivar residues from Virden and

Duke had the greatest adverse effect on total weight, and only Duke for grain yield. All other barley cultivar residues were intermediate in their effect on the growth of the two canola cultivars. In the 1993 site-year at Ellerslie, there were again differences among barley cultivar residues. However, the barley residues causing the least adverse effect and the most adverse effect were different from the 1992 site-year. In 1993, Leduc had the least adverse effect and Bonanza and Noble the greatest. There was no significant interaction observed between the three factors of tillage system, barley cultivar residue, or canola cultivar at the Ellerslie site in the years 1992 and 1993.

Table 3.20. The effect of tillage system on the yield of a subsequent canola crop when grown with nine different barley cultivar residues.

Site-year	Yield Measurement t ha^{-1}, except for Harvest Index that is a ratio.	CT	MT	DS	Coefficient of Variation (%)
Ellerslie 1992	Total Weight	11.9 a	10.0 b	12.1 a	16.0
	Grain Yield	3.9 a	3.3 b	4.0 a	19.8
	Straw Yield	8.0 a	6.7 b	8.1 a	15.7
	Harvest Index	0.33 a	0.33 a	0.33 a	7.9
Ellerslie 1993	Total Weight	6.8 b	8.5 a	9.4 a	17.8
	Grain Yield	1.9 b	2.4 a	2.7 a	23.6
	Straw Yield	4.9 b	6.1 a	6.8 a	18.7
	Harvest Index	0.27 a	0.28 a	0.29 a	12.6

Differences in letters among tillage systems within a site-year and yield measurement indicate a difference at P=0.05.

The additional factor of the type of soil type is important to consider. If the adverse allelopathic effect from the residues was less when the soil has organic matter and a finer texture, this would have practical application in that residue management to avoid adverse allelopathic effects would be more important when growing crops on low organic matter and coarse textured soils compared to high organic matter and fine textured soils. Yankle and Cruse (1984) measured the different adverse allelopathic effect of corn residues collected shortly after grain harvest when subjected to different treatments. Two of the treatments included leaching through sterilized soil, and incubation with soil. It was observed that corn residue mixed with tap water alone at day zero, inhibited root growth the most compared to any other treatment. Filtering the extract of water mixed with residue through sterilized soil reduced the inhibition of root growth. Mixing the residue with soil and water, followed with incubation greatly reduced the amount of inhibition of root growth. Apparently just filtering the extract through sterilized soil caused some of the potential allelopathic compounds to adhere to soil colloids or organic matter. Incubation with soil resulted in microbial decomposition of allelopathic compounds, and only slight inhibition of corn root growth compared to the tap water check. This research helps explain why adverse allelopathic compounds can be shown in some cases to affect germination, and early root and shoot growth in laboratory experiments, but when the residues are tested in the greenhouse in the field where the residues are left on the surface or mixed with soil the adverse allelopathic effects are observed to have less of an effect. Tie-up of allelochemicals by soil organic matter and soil clay colloids, as well as microbial decomposition reduce the possibility of allelopathic effects.

Table 3.21. The effect of barley cultivar residues on the growth of canola, Ellerslie in 1992, and Ellerslie in 1993.

Barley Cultivar Residue	Total Wt. t ha^{-1} 1992	Grain Yield t ha^{-1} 1992 *	Straw Yield t ha^{-1} 1992	H.I. 1992	Total Wt. t ha^{-1} 1993	Grain Yield t ha^{-1} 1992	Straw Yield t ha^{-1} 1993	H.I. 1993
Abee	10.9 ab	2.3 ab	7.3 ab	0.28 a	8.2 ab	3.6 ab	5.9 ab	0.33 a
Bonanza	11.4 ab	2.0 b	7.6 ab	0.28 a	7.2 b	3.8 ab	5.1 b	0.33 a
Condor	12.7 a	2.5 ab	8.5 a	0.28 a	8.8 ab	4.2 a	6.3 ab	0.33 a
Duke	9.9 b	2.3 ab	6.6 b	0.29 a	7.9 ab	3.3 b	5.7 ab	0.33 a
Harrington	11.1 ab	2.3 ab	7.5 ab	0.27 a	8.4 ab	3.7 ab	6.1 ab	0.33 a
Heartland	11.7 ab	2.6 ab	7.9 ab	0.30 a	8.8 ab	3.8 ab	6.4 ab	0.32 a
Leduc	11.5 ab	2.7 a	7.7 ab	0.28 a	9.4 a	3.8 ab	6.7 a	0.33 a
Noble	11.9 ab	2.1 ab	7.9 ab	0.29 a	7.3 b	4.0 ab	5.3 b	0.34 a
Virden	10.5 b	2.4 ab	7.2 ab	0.29 a	8.3 ab	3.2 b	5.9 ab	0.31 a

H.I. = Harvest index

Different letters within a column indicate a difference at P=0.05, or * at P=0.10.

In the field experiments interactions between different cultivar residues and different tillage systems when growing subsequent crops were observed in only one out of four site-years. That is one out of two site-years for canola cultivar residues affecting barley cultivar growth, and zero out of two years for barley cultivar residues affecting canola cultivar growth.

The degree of adverse allelopathicity was less than that observed in the laboratory or greenhouse and does not appear to be of great concern in a field situation. Phytotoxicity occurs through two mechanisms: toxin can be leached directly from fresh plant residues, or it can be produced by microorganisms during the decomposition period. Phytotoxicity is dependent not only on the species of residues but also on the length of time they take to decompose (Kitou and Yoshida 1993). If the allelochemicals are a result of the first mechanism as described by Kitou and Yoshida, the longer residues are allowed to be subject to the effects of the environment the less allelopathic effects will be observed. They also reported that there was an interaction between the length of time of decomposition of crop residues and the relative amount of phytotoxicity on a subsequent crop, with decreasing phytotoxicity over time. Thorne et al. (1990) concluded that new wheat straw was observed to have greater adverse allelopathic effects than old wheat straw. Martin et al. (1990) also concluded that the degree of inhibition of germination and growth, of crop residues on a subsequent crop species depends on such factors as the age of the residues, the nitrogen composition, and the activity of microorganisms. Older residues tended to be less inhibitory, lower nitrogen content was less inhibitory, and less microbial activity caused by lower temperatures was associated with lower amounts of inhibition. Purvis reported that unleached and undecomposed residues of sorghum, sunflower, field pea, wheat, and canola were more inhibitory to wheat growth and yield than leached and decomposed residues (Purvis 1990). Similarly Rainbault et al. (1990) observed that the longer the time period between when a fall rye cover crop was controlled using tillage or a non-selective herbicide in the spring before planting of corn the less the adverse allelopathic effects on the corn crop. Koch et al. (1992) reported that toxin liberation from winter wheat straw was high at the beginning of extraction and decreased to very low after 60 hours of extraction. They also observed that allelochemicals were absent in extracts from aerobically rotted straw, and they thought that under the cropping systems at Gottingen, Germany, there was little need for concern about winter wheat residues affecting subsequent crop growth. Although a crop residue may have adverse allelopathic effects initially, the amount of effect could change significantly with time (Thompson 1992).

These observations could help explain why reduced growth was observed in the laboratory, and during early growth in the greenhouse, but was not always observed in the field. In the cases of all field experiments reported in this study the residues were subject to physical and microbial weathering from the time of harvest in the fall, through winter and early spring until seeding and through the growing season into the fall of the following year when the subsequent crop was harvested. The effective concentration of any possible allelopathic compounds is usually reduced over time. Leaving crop residues on the soil surface rather than incorporating them with tillage will expose the residues to breakdown by ultraviolet radiation from sunlight (Janzen 1994). Crop residues on the surface under MT or DS cropping also increases the potential for phytotoxic compounds present in crop residues to be leached by water from precipitation and the water soluble compounds that are responsible for adverse allelopathic effects to leave with runoff water. Glenn and Williams (1985) measured higher concentrations of and total loading of runoff waters with potentially phytotoxic compounds, from a watershed cropped using no-tillage compared to another of similar size cropped using conventional tillage.

The presence of organic matter and clay colloids in field soils tend to tie-up allelopathic compounds through electrostatic attraction of the allelopathic molecules to the humic acids of the organic matter and the dominantly negatively charged clay colloids in the soil. This was indicated in the greenhouse experiments of this study when allelopathic effects of the barley or canola residues were much more observable in the sand compared to the topsoil.

3.4 Conclusions

There were differences among cultivar residues in the amount they adversely affect another crop species germination as observed in the laboratory. Also, there were differences among cultivars within a crop species as to how they germinate in the presence of residue extracts, and there were observable interactions between the residue types and cultivar types. This was observable for both canola residues affecting barley germination and barley residues affecting canola germination. In the greenhouse, the same differences among residue types and subsequent crop cultivars were also observable. However,the interactions between these two factors were not as easily observed as in the laboratory.

There are differences in the degree of allelopathic effects and perhaps the types of allelopathic compounds present in the residues of different cultivars within a crop species. The ability to tolerate these adverse allelopathic compounds from the residue of a previous crop differs among a group of cultivars within a crop species, grown as a subsequent crop.

The location of residues, whether left on the soil surface or mixed into the soil can result in differences in the degree of adverse allelopathic effects. Leaving the residues on the surface, as done in the greenhouse experiments of this study had less adverse effect on germination, emergence and growth of the subsequent crop than if the residues were mixed into the soil. The concern that allelopathic effects from a previous crop residue will be greater under DS than CT (Harper 1987) is not supported by the results of this set of experiments in central Alberta.

It is also important to realize that if there is less subsequent crop growth under DS compared to CT or MT, the reduced growth may be due to the physical effects of the previous crop residue. For example residues left on the surface of the soil, as done in MT or DS, may cause an impedance of light (Teasdale 1993), and cooler soil temperatures (Teasdale and Moher 1993), rather than allelopathy.

3.5 References

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CHAPTER 4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Tillage System by Cultivar Interaction

A considerable number of growers on the Canadian Prairies are switching to DS and MT from CT. All indications from recent grower surveys are that the use of DS and MT will continue to increase. In the series of experiments in this study, interactions between tillage systems and cultivars (TxC), were observed in one out of four site-years for canola, two out of five site-years for barley, and in zero out of three site-years for field pea. The interactions observed in both the canola and barley were not consistent, nor of great enough effect to justify wide scale changes in existing breeding and potential new cultivar evaluation programs. The effect of site-year or environment, greatly affected both the cultivars and the tillage systems. This is not to conclude that tillage systems by cultivar interactions do not exist, but rather under field conditions in Central Alberta it is probable that those cultivars that grow and yield well compared to other cultivars of the same crop species under CT will probably perform similarly under MT and DS.

These results compliment similar studies using similar or different crop species in different cropping regions. For example Elmore (1991) reported in an initial three year study showed that TxC interactions were observed in one of the three years. Additional research was done for two years at one site in an attempt to better characterize the TxC interaction. However in neither of the two additional years of research were any TxC interactions observed. The nature of TxC interactions is such that it is difficult to predict. There is a diversity of genetic traits among different genotypes within a crop species that can show up as TxC interactions, but there are so many other factors such as weather, planting date, seeding depth, seed drill opener design, previous crop residue type, and so forth, that affect how well a cultivar grows. The specific or more suitable adaptation of a genotype to one tillage system rather than another is of minor effect.

When the three seedbed environments resulting from the three tillage systems employed in this study are compared the environments are not that much different from one another. Similarities are far more common than any minor differences. The same soils are used, the same crops are grown, the climate consisting of air temperatures, solar radiation , and precipitation are not controlled by the tillage systems and interact resulting in small differences in early spring soil temperatures and moisture contents. Other similarities include the demand for and availability of plant mineral nutrients from the soil and fertilizer sources, as well as only small observable differences in the incidence of crop diseases (Evanylo 1990, and

Ditsch and Grove 1991). Admittedly this study was confined to spring seeded crops, and over winter survival of the crop seedlings is not a factor. For fall seeded crops such as winter wheat the DS tillage system has been shown to be superior for increasing winter survival (Fowler 1983, and Cox and Shelton 1992).

Another reason it is difficult to observe consistent and repeatable tillage system by cultivar interactions when conducting experiments as done in this and similar studies, is that the majority of micro-environmental differences among the tillage systems are soil based. The soil environment is where root growth occurs and is not easily observed or well understood. Zobel (1992) has explained that a given soil environment is the result of a multitude of interactions between many aspects of the soil. Because DS and MT affect somewhat the soil environment differently, compared to CT, a shift in the interactions of soil aspects is realized. This shift in turn interacts with the crop genotype and the resulting differences in crop growth are not easily explained.

Zobel further explained that modern science is predominately deductive in design and analysis. This deductive approach requires experiments where the number of changing variables are reduced to a minimum. Conducting studies in the field and trying to observe whether there are consistent tillage system by cultivar interactions is challenging to impossible. The natural soil environment consists of a complex of many different and interacting factors.

No previous tillage system by cultivar research has been reported for canola. This study indicates that the only minor TxC interactions exist when canola cultivars are grown using different tillage systems. Extensive research is not recommended to determine whether it would be advantageous to select for specific adaptation to MT or DS tillage practices. This may be due in part to the limited variability within the existing canola cultivars to result in different growth and yield when grown under the different seedbed conditions of DS and MT compared to CT. Earlier work done by Acharya et al. (1983) in Saskatchewan showed that existing populations of *Brassica napus* and *Brassica rapa* had limited variability for low temperature germination and growth. Progress in selecting for improved growth under cooler soil conditions would require using new germplasm adapted to lower soil temperatures for crossing with existing cultivars. The results of the experiments in this study where canola was grown indicate that genetic variability among the five cultivars used in relation to adaptation to one tillage system over another is limited. However, it is also possible that because all five of the canola cultivars grew quite well, and similarly when CT, MT and DS were used the cultivars are all equally adaptable to the different tillage systems. The barley cultivars used in this study showed a greater amount of TxC interaction than the other two species investigated. This would indicate more genetic variability present among the barley cultivars and a greater opportunity to select for specific adaptation to MT or DS within barley genotypes. As MT and DS use continues to increase especially in some regions, the tillage system employed for the regional testing of potential new cultivars could be DS or MT. This agrees with the opinion of Smith and Zobel (1991) that regional testing of new and potential cultivars be grown using as near as possible the cropping practices used by the growers of that region. All cultivars of field pea were equally adapted to the three tillage systems used in this study and any one of the three tillage systems could be used when conducting evaluation trials.

All of the field experiments were planted into spring wheat residue. This was done to avoid any within-species transfer of root or foliar diseases. The studies could have been conducted with an additional factor of previous residue species type. For example, rather than seeding the barley, canola, and peas into only wheat residue, the seeding could have been done additionally into barley, canola, and pea residue. However, the benefits of rotating crop species has been well documented for CT (Campbell et al. 1990) and there is no reason to expect that these benefits will not be realized when using MT or DS. Therefore, it is a more efficient use of resources to evaluate whether there is a TxC interaction for a specific crop species when the crops are planted into a different crop species residue. In this way, intraspecific diseases and autotoxic allelopathic effects are avoided. Spring wheat, was used as part of the design of the two sets of experiments, it is part of a normal crop rotation sequence for Central Alberta. However in some areas a common rotation may include barley planted into barley, or spring wheat planted into spring wheat. Rarely is canola planted into canola residue or field pea planted into field pea residue. The disease carry over in these crops can result in severe yield limitations in contrast to the same crops grown in rotation with small grain cereals. The experiments in this study concentrated on studying the interaction between the cultivars within one species and the three tillage systems. The problem of disease carry-over from residues of the same crop species being more or less of a problem under MT and DS compared to CT was purposely avoided. This is not to say that this type of research is not important or needed, but would require significant resources of time and funding that were not possible within the frame work of this study.

4.2 Cultivar Residue Effect on a Subsequent Crop as Affected by Tillage System

This second set of experiments complimented the tillage system by crop cultivar study and added another dimension to the research. There has been limited research done studying the allelopathic effect of residue management under different tillage systems. In the laboratory, interactions were readily observed between source cultivar residue type and target cultivar type. Similar research done in the greenhouse showed that there were differences among the source cultivar residues and the target cultivars, but the interactions between these two factors were much less observable than in the laboratory. Also, the factors of growth medium and residue management system (surface applied or mixed, simulating respectively DS and CT), greatly affect crop growth. Soil having organic matter and clay colloids present resulted in less adverse allelopathy. Leaving the residues on the soil surface had less adverse allelopathic effect than mixing the residues into the soil. This second observation is in contrast to management recommendations in some regions that call for incorporation of previous crop residues to avoid adverse allelopathic effects (Harper 1987). Under Central Alberta conditions, interactions between source residues and tillage systems were observed in only one of the four site-years of the two related experiments in the field. This would indicate that although the residues from different cultivars have the potential to differentially affect subsequent crops when different tillage systems are used, it is unlikely that the differences are large enough to warrant cultivar screening and selection to warrant cultivar selection for source or target cultivars to lessen adverse allelopathic effects.

In the field, potential allelopathic chemicals in the residues are subject to weathering from sunlight, leaching from precipitation, immobilization by adsorption onto organic matter and clay colloids, as well as being metabolized by soil microbes. The window of time for observable effects from potential allelopathic compounds originating from crop residues appears to be shorter than the time between harvest in the fall and seeding of a subsequent crop the following spring. This may not be the case when seeding a fall seeded crop such as winter wheat into soil that has residues present from a recently harvested crop, seeded the spring of the same year. It is recommended that a study be conducted to determine the potential adverse allelopathic effects of different cultivars within crop species be evaluated for the seeding of winter wheat. The study should include a range of cultivars from both the target crop or the winter wheat as well as the source or residue crop, with different species of the source crop also included.

As DS and MT use increases for spring seeded crops, there need not be any greater concern for possible allelopathic effects under DS and MT compared to CT. Allelopathic effects do exist, in that different cultivars within a crop species do exhibit different tolerance to allelopathic compounds, and residues from different cultivars within a crop species potentially have more or less adverse allelopathic effects on subsequent crops. However when all other possible growth factors come into effect in the field, allelopathy will tend to be a minor factor. The exception could be on coarse textured or low organic matter soils compared to finer textured or high organic matter soils, as possibly indicated by the greenhouse experiments in this study. This is another suggested topic for further research.

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