THE IMPACT OF SEED TREATMENT, CULTIVAR AND CROP DENSITY ON CANOLA (*BRASSICA NAPUS*) COMPETITIVENESS AGAINST VOLUNTEER BARLEY (*HORDEUM VULGARE*)

BY

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A Thesis
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In Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

Department of Plant Science
University of Manitoba
Winnipeg, Manitoba

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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Abstract

Canola is an important crop in western Canada that has become intensively managed with purchased inputs. By knowing the relative contribution of seed treatment, seeding rate, and cultivar to canola competitiveness against weeds and yield producers can adjust input decisions and maintain yield goals but increase net gain. Field experiments took place during 1999 and 2000 in the Brandon region of western Manitoba. Treatments included; two canola cultivars (Invigor 2273 & Exceed), the presence/absence of volunteer barley, four target canola densities (37.5, 75, 150 & 300 plant/m^2) and four seed treatments (non-treated, mixture of thiamethoxam, difenoconazole, fludioxonil and metalaxyl-M (Helix), and a mixture of lindane, carbathiin and thiram (Vitavax RS) with and without furrow placed terbufos (Counter). Using greenhouse experiments we examined the effect of seed treatment on canola's competitiveness in the absence of pests using a target neighbour design. In general, cultivar and seeding rate influenced canola growth, yield and competitiveness greater than seed treatment. Crop stand was only affected by seeding rate. Seed treatment offered excellent protection from flea beetles, but protection did not always translate into improved canola growth, weed suppression or yield gain. In the absence of pests Vitavax RS hindered canola competitiveness, while Helix was similar to bare seed. The hybrid variety Invigor was more competitive with weeds and higher yielding than Exceed canola. Early, vigorous seedling growth resulting from using a seed treatment may not be as important for canola competitiveness as vigor from heterosis and crop density. Thiamethoxam was a good replacement for the environmentally problematic lindane for flea beetle management; however, producers with moderate to low flea beetle infestation

or those interested in integrated pest management may be better off increasing seeding rate or using a hybrid variety to help control weeds and better optimize yield.

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Introduction

Canola (*Brassica napus* L.) has become a very important crop for western Canada. Over the last ten years canola acreage has increased 121% going from just under 2.5 million hectares in 1990, to 5.5 million in 1999 (Canola Council of Canada, 2000). Saskatchewan contributes the most acres (46%) followed by Alberta (36%), then Manitoba (18%), but Manitoba on average experiences some of the highest yields (Canola Council of Canada, 2000). Combined, all three provinces produced 8.6 million tonnes of canola seed in 1999 worth 2.1 billion dollars, 450 million of which went to Manitoba (Canola Council of Canada, 2000).

Canola has become a very input intensive and expensive crop to grow. Weeds, insects, and fungal pathogens all contribute to reducing quality and yield (Blackshaw et al., 1987; Lutman et al., 2000; Marshalll et al., 1988; O'Donovan, 1991; Ogilvy, 1989). The magnitude of these pest problems is revealed by the amount of money producers spend on control. For example, of the one billion dollars spent on pesticides in western Canada in 1998, producers spent a total of 316.8 million dollars (31%) on pesticides in canola (Crop Protection Institute, 2000). Of the 316.8 million, two hundred and seventy two million (82%) was spent on herbicides, twenty two million (7%) was spent on insecticides, and another 22.2 million (7%) was spent on fungicides (Crop Protection Institute, 2000). The amount of insecticide and fungicides may seem low in regards to other crops, but 72% of the money spent on insecticide in western Canada was for canola and 45% of all the money spent on fungicides was on canola (Crop Protection Institute, 2000). These statistics point out the importance and magnitude of weed control in canola production, but also the role insecticides and fungicides play in canola production relative to other crops.

As indicated by the amount of money spent on herbicides, weeds are the primary source of yield loss in canola. Even with good management practices, producers still lose 10% of their canola yield to weed competition, resulting in an average annual loss of eighty million in revenue (Swanton et al., 1993). Grassy weeds are some of the most common and most competitive weeds in canola fields (Lutman, 1989; Thomas et al., 1997. Among the grassy weeds, volunteer barley (*Hordeum vulgare*) is one of the most competitive against canola (Marshall et al., 1988; Lanning et al., 1997). Barley produces more biomass than either wild oats (*Avena fatua*) or volunteer wheat (*Triticum* aestivum) which allows less light penetration into the canopy (Marshall et al., 1988; Lanning et al., 1997). Barley's competitiveness along with it's germination predictability make it a good test weed species for plant competition studies.

The flea beetle (*Phylotreta cruciferae*) is an important pest affecting canola in western Canada (Lamb, 1984; Weiss et al., 1994). Unlike the other pests, flea beetles attack canola as soon as young seedlings emerge, feeding on the hypocotyl and cotyledons (Lamb, 1984). Flea beetles can seriously damage young canola plants, which inhibits growth or kills plants altogether (Lamb, 1984; Westdal & Romanow, 1972.). Estimated losses due to this pest are difficult to determine but total crop elimination can occur, especially during hot dry weather (Lamb & Turnock, 1982).

Soil-borne pathogens are found in all soils through-out western Canada although they are more prevalent and destructive in the Peace River region of Alberta causing diseases such as damping off and root rot (Berkenkamp, 1972; Petrie, 1973; Berkenkamp & Degenhardt, 1974; Sippel et al., 1985). The mycelia of these organisms attack canola during the early stages of emergence by penetrating rootlets and exhausting them of all

nutrients (Martens et al., 1994). If plants are not killed they are left with very underdeveloped roots, slowing growth and development (Martens et al., 1994). In the Peace River region, damage can be as high as 80-100% stand loss depending on soil conditions (Yang & Verma, 1992). It is estimated than on an annual basis these organisms are responsible for 8-18% yield loss in western Canada (Martens et al., 1994).

Seed treatments containing systemic insecticides and fungicides are used to control flea beetles and damping off diseases. These chemicals are absorbed through the seed coat and translocated to the cotyledons where they protect seedlings during the early and most susceptible time in their development (Kataria & Verma, 1993). With the future elimination of the insecticide lindane from the market some producers are worried they will be losing an important tool for pest management.

During the time when canola seedlings are vulnerable to both flea beetle attack and fungal invasion, the initiation of weed competition occurs (Martin, 1999). A possible connection between these pests has never been investigated. Flea beetles and soil-borne pathogens reduce plant vigour (Lamb, 1984; Westdal & Romanow, 1972; Martens et al., 1994) and interfere with the rate of canopy closure. By protecting the crop from these organisms or modifying agronomics, producers may increase the suppressive ability of canola and as a consequence, increase the effectiveness and efficiency of insect and weed control, ultimately optimizing yield. An understanding of the impact these inputs have on canola growth, canopy development and weed competition would be very useful in determining the value these inputs contribute to canola production.

Literature Review

General Concept of Space Capture and Canola Yield

In order for canola to reach it's yield potential it must intercept an optimum amount of radiation while capturing all nutrients required to grow and maintain biomass needed to support reproductive structures (Loomis & Amthor, 1999). Growth in response to space is a broad concept describing plant consumption of all available resources in that space, with resources including water, soil nutrients and light (Harper, 1977). The more space occupied or captured by a plant, the more resources it has been able to consume (Harper, 1977).

Photosynthesis and respiration are the processes plants use to synthesise and maintain biomass during space capture, with the cost of maintenance increasing as vegetative biomass accumulates during the season (Loomis & Amthor, 1999). The efficiency at which plants regulate photosynthesis and respiration for growth and maintenance depends on plant genetics and environmental conditions (Loomis & Amthor, 1999). The potential yield of a crop is either the biomass or seed yield of a cultivar when grown in environments to which it is adapted with all stresses effectively removed. (Evans, 1993). Crops are at the mercy of variations in weather, supplies of water and nutrients, the occurrence of pests and disease, and plant density (Loomis & Amthor, 1999). How plants cope with changes in these factors describe it's plasticity (Crawley, 1997).

Phenotypic plasticity refers to a species ability to adjust it's physical dimensions or behaviour during it's growth in response to environmental change (Crawley, 1997). Phenotypic plasticity in plants is very important, allowing self modification by the birth

or death of plant parts to best suit the potential of the environment and therefore maximise its chances of reproducing (Harper, 1977).

In relation to plant density, plants differ in genetic limits regarding how much space they can capture. Canola is a very plastic plant due to it's indeterminate growth habit. In contrast, a monocot such as volunteer barley displays determinant growth meaning the terminal meristem is used up in flowering (Harper, 1977). As a result, its growth potential in terms of space capture is somewhat more limited, responding to more space by simply increasing tiller production (Davis et al., 1994; Lafarge, 2000; Radosevich et al., 1996). This does not mean barley is less competitive than canola. It only means canola is able to take advantage of more space if available. When space becomes more limiting, the amount of space a plant is able to acquire depends on restrictions imposed by neighbours for growth rate or growth duration (Harper, 1977) and competition for resources occurs. Competition between plants of the same species is referred to as intra-specific competition, while competition between different species is inter-specific competition.

Due to canola's phenotypic plasticity, row spacing and planting density do not have a large influence on yield under weed free condition (Degenhardt & Kondra, 1981; McGreggor, 1986; Morrison et al., 1990). Even at low density and wide row spacing, canola takes advantage of vacant space by increasing stem girth and branching, thus yielding more per plant (Degenhardt & Kondra, 1981; McGreggor, 1986; Morrison et al., 1990). The reverse is true at high density. As intra-specific competition increases, the proportion of large plants becomes smaller and smaller (Harper, 1977; Crawley, 1997), with the majority of canola plants being individual shoots, each contributing only a small

amount to overall yield (Morrison et al., 1990; McGreggor, 1986; Degenhardt & Kondra, 1981). The modification of individual plant yield in response to increasing levels of intra-specific competition is called the law of constant yield (Harper, 1977). For canola, grain yield increases sharply from 0-80 plants/m^2 then plateaus from 80 to 300 plants/m^2 before starting to decrease (Canola Council of Canada, 2000). The only factor that changes for different planting densities is the time to which constant yield is achieved. Since plants get larger and in effect closer together as time goes on, space and time are closely related (Harper, 1977; Aldrich, 1987). Canola seeded at low density may yield the same as canola seeded at high density but it will take longer because there are fewer plants having to grow much larger to fill the same amount of space (Morrison et al., 1990; McGreggor, 1986; Degenhardt & Kondra, 1981).

The constant yield ceiling exists because there are limiting resources that restrict further crop growth (Aldrich, 1987). At this point, the supply of resources sets the limit to biomass produced per unit area, with a further increase in density having little effect on yield (Aldrich, 1987). Factors causing the yield ceiling may be temperature, water, nutrients, or light. Removing the limiting factor permits further growth which translates into more biomass and seed, provided all other stress is minimal. Soil fertility influences constant yield by either increasing or decreasing the maximum potential yield (Harper, 1977). Providing more nutrients per unit area has the same effect as allowing more area per plant. Increasing total resources increases overall potential yield (Harper, 1977) and vice-versa.

In agriculture, nutrient levels are usually kept as optimal as possible through the addition of fertilizers, resulting in the growth rates of weeds and crops nearly

proportional to light intercepted (Radosevich et al., 1996; Aldrich, 1987). Photosynthesis supplies the energy involved in growth, reproduction, and transpiration. In C_3 plants such as canola and volunteer barley, photosynthesis is restricted by leaf CO_2 concentration due to plant physiology (Loomis & Amthor, 1999). Under stress free conditions, CO_2 concentration becomes more limiting as light intensity increases, with the photosynthetic rate ultimately reaching a maximum (Loomis & Amthor, 1999). During early establishment CO_2 may be the limiting factor since there is no canopy closure and all initial leaves are fully exposed to light. During initial establishment and under optimal soil nutrient conditions plant growth is exponential, limited only by temperature and in the case of C_3 plants, CO_2 concentration (Kropff, 1993).

Plants that grow fast in early developmental stages, often have a strong advantage and can build up a larger share in the canopy (Kropff, 1993). Once there is mutual shading of leaves, a crop canopy has established (Kropff, 1993). As the crop canopy develops, fewer and fewer leaves are exposed to light intensity sufficient enough for CO_2 concentration to limit photosynthesis, so provided all other resources are optimal, light is usually the most limiting resource (Loomis & Amthor, 1999; Radosevich et al., 1996). Since light resources often becomes the limiting factor, it usually restricts the extent to which added soil nutrients will increase the constant yield of crops (Harper, 1977; Radosevich et al., 1996).

Crop yield ultimately depends on the length of the growing season, which determines the maximum amount of light a crop canopy can intercept (Monteith, 1981). Intra-specific competition for light sets the upper limit for constant yield. Season length along with genetic plasticity limit how low canola density can be while maintaining

constant yield. Due to growth rate, canola seeded at very low seeding rates simply run out of time for capturing equal amounts of resources relative to canola seeded at higher density. At any density, conditions that slow the growth rate will tend to extend the time that crop yield is related strictly to density (Aldrich, 1987).

Another way space capture may be modified for canola is by using hybrid seed. How much space a plant is able to capture depends on its starting capital which, is related to embryonic weight and seed reserves (Harper, 1977). Hybrid canola seed is generally larger, permitting a greater amount of reserves during emergence (Milborrow, 1998). Due to heterosis, hybrid plants have higher growth rates and therefore accumulate biomass at a faster rate than open pollinated plants (Milborrow, 1998). These characteristics allow hybrids to increase their rate of space capture, acquiring more resources under the same light and temperature restrictions, ultimately extending constant yield limits imposed on non-hybrid varieties (Harper, 1977). A consequence of having faster growth is that the onset of intra-specific competition or interaction with neighbours (other canola plants) also occurs sooner due to faster resource depletion (Harper, 1977).

Since time and space are closely related (Harper, 1977; Aldrich, 1987), by decreasing the time to neighbour interaction, the restrictions of the law of constant yield would be expected to apply at lower density sooner to hybrid canola versus non-hybrid, both seeded to equal densities. By reaching constant yield sooner, one might think hybrid canola would shift the density yield response curve slightly to the left, suggesting a somewhat lower seeding rate in relation to open pollinated varieties; however, studies have shown very little difference in the density-yield response of hybrid versus open

pollinated canola and as a result they have the same suggested seed rate of 4-6kg/ha (McVetty et al., 1988; Van Deynze et al., 1992).

Canola and Weed Competition

There are two perspectives to consider when describing or examining the competitive potential of a crop; that of the individual plant, and that of the plant community as a whole (Harper, 1977; Radosevich et al., 1996). At the individual plant level, plants are considered a good competitor either by rapidly depleting available resources (space) or being able to continue growing at depleted resource levels (Radosevich et al., 1996). Plants species can therefore be grouped based on how they use resources. There are those species which are competitive based on superior resource uptake, minimising resource loss, or maintaining optimal efficiency of conversion of internal storage material into new growth (Radosevich et al., 1997). Since light often becomes the only limiting factor in agriculture systems (Radosevich et al., 1996), having slightly more efficient assimilation rates, or being able to survive at very low nutrient levels may not be the most competitive attributes. This leaves superior resource uptake and rapid resource extraction, both of which are associated with hybrid vigour (Milborrow, 1998). There has been no research published to-date concerning hybrid canola verses open pollinated varieties and weed competition. Work conducted with corn (*Zea mays*) however has demonstrated the added competitiveness heterosis provides (Lindquist & Mortensen, 1998). Due to fast establishment, increased height and biomass production, hybrids are better able to monopolise their environments (Lindquist & Mortensen, 1998). Among corn hybrids, the tallest varieties with erect leaves seem to yield the most and show increased suppressive ability against weeds (Roggenkamp et al.,

2000). Of all the factors affecting space capture by plants, the most important is relative time of emergence. By emerging before the surrounding plants, the crop can pre-emptively use the surrounding resources. The area of the space which each seedling pre-empts is thought to be proportional to the weight of the entire seedling (Harper, 1977). A plant is assumed to stop growing when it's potential space is completely captured by neighbours, with the space available within a zone being more critical than the position of the plants within that zone (Harper, 1977).

Timing is important because once a difference between two neighbours is triggered, it is progressively exaggerated (Harper, 1977). This exaggeration can result from two different or compounded circumstances. If the competing plants have constant but different relative growth rates, a difference in size will appear between them and increase with time (Wilson, 1988). The other way is that the effects of competition might magnify differences in competitive ability (Wilson, 1988). For example, if there are two seedlings and one has larger leaves due to either earlier emergence or genetic reasons, and this difference results in a competitive advantage, that advantage would become greater with time because increased growth would increase the size difference even more, thus further increasing the initial advantage (Wilson, 1988).

The influence relative time of emergence has on competitiveness has been demonstrated with studies using barley and canola, wild oats and barley, and wild oats and wheat (O'Donovan et al., 1985, O'Donovan, 1992). At any given weed density, crop yield decreased and weeds had higher yield the earlier the weed emerged relative to the crop (O'Donovan et al., 1985, 1992) For example, Barley emerging two days before

canola reduced canola yield more than barley emerging two days after (O'Donovan, 1992).

At the community level, suppressive ability is related to plant density which alters the intensity of intra-specific and inter-specific plant competition (Harper, 1977). Intra-specific competition for resources between plants is usually more intense than inter-specific because plants of the same species occupy the same environmental niche (Harper, 1977). Having the same environmental niche means all plants are trying to access equal proportions of resources from relatively the same dimensional area at the same time (Harper, 1977; Radosevich, 1996). The way a crop increases it's suppressive ability with increased planting density is simply power in numbers (Harper, 1977). Even though there is a high level of intra-specific competition at high density, provided both the crop and weed emerged at the same time, the extra plants mean there is less space between the crop and weeds. The decrease in space also means a decrease in the time of the onset of both intra-specific and inter-specific competition.

Having plants in close proximity to a weed, places early stress on that weed indicating it has less potential space because of its close neighbours (Harper, 1977). The weed's growth potential is diminished but because of the law of constant yield, the yield potential of the entire crop is not (Harper, 1977) and weeds are suppressed. The more space a weed is allowed in the beginning, the more area it will be able to pre-empt because the onset of competition is delayed (Harper, 1977). The longer weeds are able to continue their growth, or the more of them there are, the more resources they remove from the soil and possibly lowering the constant yield ceiling relative to if weeds were not present (Aldrich, 1987).

Once beyond the seedling stage, canopy closure is a very important element of weed suppression (Radosivich et al., 1996). Increasing seeding rate means each plant only has to grow for a fraction of time to achieve canopy closure relative to lower planting densities. A plant's ability to project its canopy over that of a neighbour can impart a considerable competitive advantage with respect to light capture, if it occurs early in the life cycle or at a particularly critical development stage (Radosivich et al., 1996). As mentioned earlier, one of the reasons barley is a very competitive plant is it's ability to minimize light penetration into it's canopy (Lanning et al., 1997).Work examining how canola density effects weed suppression has been done using many weeds including; Chickweed (*Stellaria media*) (Lutman et al., 2000), Canada thistle (*Cirsium arvense*) (O'Sullivan et al., 1985), quackgrass (*Elytrigia repens*) (O'Donovan, 1991) , volunteer wheat (*Triticum aestivum*)(Vera et al., 1987; O'Donovan et al., 1989), tartary buckwheat (*Fagopyrum tataricum*) (O'Donovan, 1994), and volunteer barley (*Hordeum vulgare*) (O'Donovan, 1988; Ogilvy, 1989). In all cases weed suppression increased with increased seeding rate. However, due to differences in plant competitiveness the increase in suppression relative to increased seeding rate was not proportionally equal for all weeds.

As previously mentioned, another way to increase space capture without increasing the seeding rate is to increase the growth rate of the crop, either by using hybrid crops or protecting the crop from pests. Any circumstances that slow the growth rate of young plants will extend the time the number of weeds present mainly determines crop yield (Aldrich, 1987). Increasing growth rate would then decrease the time to the onset of competition and increase the rate of canopy closure and shorten the time period

weeds are able to influence potential yield. As a result, hybrid plants or plants protected from pests may maintain their weed suppressive ability when planting density is lowered.

Specific Agronomic Issues Affecting Space Capture and Canola Yield

1. Damage Caused by Flea Beetles

There are two species of flea beetle (*Phyllotreta cruciferae*) in western Canada responsible for damaging canola (Wesdal & Romanow, 1972). They are both very small in size (2-3mm), either black in color with a bluish sheen or black with two yellow stripes (Wesdal & Romanow, 1972). Flea beetles emerge from over-wintering sites as adults in mid-April to mid-May (Wesdal & Romanow, 1972). Flea beetles never over-winter in fields, instead seeking shelter in leaf litter, wind breaks or wooded areas adjacent to farm land (Wesdal & Romanow, 1972). After emerging, they proceed into the fields from the perimeter regions feeding on volunteer canola(*Brassica napus*), wild mustard (*Brassica kaber*), flixweed (*Descurainia sophia*) or peppergrass (*Lepicium densiflorum*) seedlings until the canola crop emerges (Wesdal & Romanow, 1972; Canola Council of Canada, 2000). Once the crop has emerged, feeding commences and breeding takes place. Females lay eggs in the soil were larva hatch and feed on the canola roots (Wesdal & Romanow, 1972). Larva feed for a period of 3 to 4 weeks then progress to a brief pupa stage before emerging as adults in early to mid August (Wesdal & Romanow, 1972). Adults feed on the green material of canola and related plants until mid September to mid October before returning to over-wintering sites and starting the cycle again (Wesdal & Romanow, 1972).

Movement through fields is dependent on weather and more specifically temperature (Dosdall et al., 1999). During hot days (>20°C) flea beetles can fly long

distances, distributing themselves more evenly through out a field. Under cooler conditions or circumstances of high flea beetle density, the most intensive damage will be restricted mostly to the perimeter of the field (Canola Council of Canada, 2000). Since cool temperatures restrict movement, studies have shown differences between tillage system and flea beetle infestation (Dosdall et al., 1999; Milbrath et al., 1995). Due to cooler, moist conditions and increased obstruction from crop residue typical of a zero-tillage field, flea beetle movement is restricted, preventing mass migration and disabling feeding. As a result, problems associated to flea beetles in canola are greatly reduced under zero-tillage and seed treatment may not always be necessary (Dorsall et al., 1999, Milbrath et al., 1995, Tonhasca, 1994).

Flea beetles cause the most damage in the early stages of crop emergence (Lamb, 1984; Wesdal & Romanow, 1972). They prefer young seedlings, with damage decreasing as the age of the plant increases (Brodnaryk & Lamb, 1991). Flea beetles will leave older seedlings to feed on newly emerged seedlings (Bracken & Bucher, 1986) therefore, most of the plant mortality occurs during the first week of canola emergence (Lamb, 1984). Studies have shown yield and plant survival increases as plants are protected for increasing increments of time (Bracken & Bucher, 1986), The inverse of this relationship is also true, with yield and plant populations decreasing as the unprotected period increases (Bracken & Bucher, 1986). For this reason, seed treatment and not post-emergent spray is advised for protection from flea beetles (Weiss et al., 1991).

When protection against flea beetles is not used damage can be extensive, decreasing overall plant growth and height and slowing maturity (Lamb, 1984). Slower

plant growth can mean lower crop competitiveness and a decrease in resource capture (Harper, 1977; Radosevich et al., 1996). Delayed maturation means a higher green seed count leading to higher chlorophyll levels and lower oil quality (Lamb, 1984). Dosdall et al. (1999) has shown higher seeding rates as a possible substitute for seed treatment in zero-till production systems where flea beetle movement is somewhat limited due to a less hospitable environment. Since there is only one generation of flea beetles per year, increasing seeding rate saturates the food source for the flea beetle population. Overall feeding does not decrease, but damage on a per plant basis is reduced resulting in a level of feeding non detrimental to canola seedlings (Dosdall et al., 1999).

Another way of potentially limiting the impact of flea beetle feeding may be the use of resistant cultivars and work attempting to identify traits responsible for resistance has been done (Lamb et al., 1992, 1993; Bodnaryk, 1992; Bodnaryk et al., 1994, 1997; Bodnaryk & Lamb, 1991). Plant resistance to insects is through tolerance and antixenosis. Tolerance refers to the plants ability to sustain growth when damaged and to recover from damage through increased growth rate. Antixenosis results from plant traits that deter feeding insects. Plants can display both of these mechanisms or just one. Plants that grow quickly through the cotyledon stage sustain less damage and yield higher because they are better able to tolerate the smaller amount of damage resulting from a shorter vulnerable period of attack (Lamb et al., 1993). Decreases in damage was shown to be proportional to increased seed size (Bodnaryk et al., 1991). Bigger seed results in more vigorous crops which are able to accelerate through the vulnerable growth stages (Bodnaryk et al., 1991). Hybrid seed can be much larger than open pollinated seed and hybrid seedlings display more vigorous growth (Bodnaryk et al., 1994); however, they

appeared to have no agronomically beneficial resistance to flea beetle damage in one study done in 1994 (Bodnaryk & Lamb). Hybrid plants had slightly higher levels of antixenosis than open pollinated varieties, but tolerances levels were lower.

2. Soil-Borne Pathogens

The main fungal pathogen responsible for damping off and root rot diseases in canola in western Canada is *Rhizoctonia solani* (Kateria & Verma, 1992; Yitbarek et al., 1988; Teo et al., 1988). There are two isolates of this pathogen which cause disease, AG2-1 and AG4 (Teo et al., 1988). AG2-1 is mostly responsible for causing damping off disease and root rot in seedlings, with AG4 attacking mature plants, causing brown-girdling root rot disease later in the season (Kateria et al., 1992). One of the reasons for their distinction is that AG2-1 prefers much cooler growing temperatures than AG4 (Yitbarek et al., 1988, Teo et al., 1988, Kateria et al., 1992) and, therefore, the later is usually not active during canola emergence. Moisture is usually not a factor since both AG2-1 and AG4 can grow at relatively low water potentials (Teo et al., 1988).

The infection chain of soil-born pathogens consists of a non-parasitic phase involving saprophytic activity followed by primary infection or parasitic phase then a secondary infection phase arising from the primary infection (Gilligan et al., 1987) Primary infection is the product of the probability of a series of events (Gilligan et al., 1987). First there is the probability a propagule will occur close to a host. Secondly, conditions must favour spore germination, then the propagule must reach the host, infection must be initiated and finally, the host must be infected (Gilligan et al., 1987). The probabilities of spore germination and growth are related to soil nutrient conditions,

but the distance from a host and the chance of infection are related to plant density and plant growth (Gilligan et al., 1987). As the host density increases, the probability of infection increases, therefore, an increase in crop density will result in proportionally more plants infected by soil-borne pathogens (Bailey et al., 2000). The probability of the host being infected is dependent on the host's growth rate (Gilligan, 1987). The change in susceptibility is rapid, so the period between germination of a propagule and the arrival at the surface of the host may be critical in determining whether or not infection occurs (Gilligan, 1987).

The infection of canola by *Rhizoctonia solani* isolate AG2-1 is described in detail by Kateria and Verma (1992). When the AG2-1 isolate of *Rhizoctonia solani* is attacking a young canola seedling, hyphae first grow on the surface of the roots branching almost at right angles. The lateral hyphae branch bidirectionally while growing parallel to the long axis and continue to form short stout branches. The short branches tend to coil and overlap to form compact dome-shaped cushions on the surface of the root. From the underside of these cushions arise numerous hyphal pegs, which penetrate directly through the cuticle. Once inside, hyphae grow both inter-and intra-cellularly and macerate the cortical tissues by enzymic dissolution of the middle lamella. The penetration process corresponds to the probability of infection mentioned above. If at this point, the plant has developed to the point where it's cuticle is too thick (ie: too woody) then infection does not occur and the canola seedling has evaded infection.

Studies have shown an inverse relationship between percentage disease ratings and the age of canola at the time of inoculation, 70% at 1 week old and 12% at 10 weeks old (Kateria & Verma, 1992). A study screening for resistance to AG2-1 found none of

the 122 cultivars examined to be immune, but significant differences in susceptibility were present (Yang & Verma, 1992). Adult plant resistance was associated with the decrease of seed or root exudation and infection-cushion formation with seedling age (Yang & Verma, 1992).

3. Seed Treatment

One of the most common and effective seed treatments used to protect canola from both flea beetles and soil-born pathogens is Vitavax RS (lindane, carbathiin, thiram). Vitavax RS is often accompanied by Counter (terbufos), a granular product containing the insecticide terbufos that is placed in the seed furrow (Weiss et al., 1991; Lamb & Turnock, 1982). Lindane is absorbed through the seed coat and then systemically relocated through out the plant (Kataria et al., 1993). Initial concentrations decrease quickly due to rapid translocation to leaves where it is diluted, giving protection from flea beetles for around 7 days, depending on growing conditions (Westcott, 1985). The addition of terbufos extends plant protection (Szeto et al., 1986; Kataria & Verma, 1993), but since it is located in the furrow as a granular, terbufos is not active until it is taken up by the roots (Szeto et al., 1986). The chemical is metabolised relatively quickly for the first 15 days, but then decline slows considerably (Szeto et al., 1986).

There are two fungicides in the product Vitavax RS; carbathiin and thiram. Both are systemic fungicides which concentrate in the hypocotyl and roots (Kataria & Verma, 1992). Depending on the growing condition, the mixture of these fungicides has been noted to remain active in the plant for approximately 15-20 days (Kataria & Verma, 1992).

There are no studies known in regards to the impact seed treatment has on plant growth in general, but questions have been raised. Concern has been expressed about the possibility of these chemicals reducing germination and even seedling vigour (Bob Elliot personal conversation). There has also been suggestion of the opposite occurring, with certain chemicals having a growth stimulant effect on seedlings (Foster & Brust, 1995).

Lindane is currently being phased out of use in Canada (Canola Council of Canada, 1999). This is in part due to it's high mammalian toxicity, but also due to it's persistence and build-up in the environment (Kerstin et al., 1995; Hall et al., 1999; Larsson et al., 1992; Parent-Massin et al., 1997). Lindane, or gamma-HCH is fat soluble so once in the body it can be stored for long periods of time, causing it to slowly accumulate in the food chain (Larsson et al., 1992, 1997;Jung et al., 1997; Olea et al., 1999). Residues of lindane have been found in breast milk (Saleh et al., 1996; Al-Saleh et al., 1998) and lindane has been linked to many different forms of cancer and other degenerative diseases (Wolf et al., 1998; Corrigan et al., 2000). Overall, when global impact is considered, the small benefit producers gain in yield is tiny compared to the potential health risks they face for both themselves and the environment.

Helix is a representative of a new generation of seed treatments which could potentially replace lindane, offering similar control but lower mammalian toxicity. Helix is a mixture of one insecticide (thiamethoxam) and three fungicides (difenoconazol, fludioxonil, and metalaxyl-M). Thiamethoxam has shown excellent activity against a wide range of commercially important insects (Maienfisch et al., 1999), using a mode of action not broadly used for insecticides, making it better able to control insects resistant to other insecticides (Maienfisch et al., 1999). Difenoconazole is a systemic fungicide

(Dahmen et al., 1992) and fludioxonil is a contact fungicide (Cabras et al., 1997). The length of activity for this seed treatment has not been established for certain, but work with fludioxonil on grapes has shown a decay rate of approximately 24 days, depending on conditions (Cabras et al., 1997).

4. Foliar and Stem Pathogens

Though not impacting the competitiveness of canola, foliar and stem pathogens such as blackleg (*Leptoshaeria maculans*) and sclerotinia (*Sclerotina sclerotiorum*) can greatly impact yield (Martens et al., 1994). Sclerotinia is prevalent throughout western Canada (Martens et al., 1994) and though it is predominantly a soil-borne pathogen, infection occurs primarily from air-borne ascospores, with severity becoming quite high if given optimal conditions (Purdy, 1979). Canola yield reductions can be great but incidence may vary from year to year and even field to field (Martens et al., 1994). Yield loss is most severe when infection occurs at mid-flowering but rarely exceeds 15 to 20%. The most effective way of preventing this disease is by avoidance through the use of a proper rotation (Kharbanda & Tewari, 1996); however, even with a good rotation it is difficult to avoid some level of infection since there are many hosts for sclerotinia and inoculum can persist in fields for 2 years depending on soil conditions (Teo et al., 1989; Williams & Western, 1965). If weather conditions are favourable for high levels of Sclerotina infection there are many fungicides that provide effective control (Steadman, 1979).

The fungus causing blackleg over-winters on crop residue which, is the main source of infection (Rempel & Hall, 1993). Unlike sclerotinia, blackleg may also arise

from seed born mycelium (Martens et al., 1994). Even though approximately less than 2% of seed carries the infection, this may be an important long distance dispersal mechanism (Martens et al., 1994). Seed treatment is one way of preventing the seed transfer of Blackleg (Maude & Humpherson-Jones, 1984); however, studies have shown seed treatment does little to protect seedlings from infection from surrounding residue 20 days after emergence (Kharbanda, 1992). Again, proper crop rotation is the most effective cultural practice available for control (Gugel & Petrie, 1992).

Even though these diseases do not effect canola's competitiveness, agronomics can impact the incidence of disease (Kharbanda & Tewari, 1996). Both diseases thrive in humid conditions (Martens et al., 1994) and increasing plant density can create a dense canopy which retains moisture and promotes disease development (Turkington & Morrall, 1993). Although disease management is an important issue, due to the unpredictability of infection, the relative ease of control, and potential for breeding for resistance, weed management is usually first priority among producers, unless disease risk becomes extreme.

Review

Canola is currently a very input intensive crop. The purpose of inputs is to maximise the availability of resources to canola by either protecting the crop from pests or eliminating competitors. Crop pests and disease diminish the crop's ability to access resources by interfering with photosynthesis and assimilation, slowing growth or destroying plants altogether. Weeds steal light and nutrients from the crop, therefore reducing it's potential yield. Seed treatment protects emerging canola plants from soil-borne pathogens and flea beetles during the onset of weed competition, yet despite this

commonality, the relationship between plant protection and weed competition has never been investigated for canola.

The impact of canola density (O'Donovan et al., 1988, O'Donovan, 1994) and relative times of emergence (O'Donovan, 1992) on weed suppression is very strong. For this reason, rapid even establishment is very important for maximising canola yield. By increasing seeding rate to minimise the potential space available for emerging weeds, weed growth is suppressed, canola yield is increased, and weed seed return is minimised (Harper, 1977; Radosevich et al., 1996; O'Donovan et al., 1988, O'Donovan, 1992). Using hybrid varieties can also increase the competitiveness of a crop because of hybrid vigour which allows faster space acquisition (Milborrow, 1998, Harper, 1977). Flea beetles and soil-borne pathogens can greatly reduce both canola density and plant vigour (Lamb, 1984; Westdal & Romanow, 1972). Seed treatment protects emerging canola plants from both of these pests (Bodnaryk & Lamb, 1990; Kataria & Verma, 1993), thus allowing regular development.

Despite the fact that seed treatment, cultivar and seeding rate all influence stand development, the value of seed treatment relative to increased seeding rates and cultivar on weed suppression has not been examined. Due to the nature of flea beetle attack, modifying seeding rate has the potential to compensate for flea beetle damage (Dosdall et al., 1999) but the impact of this substitution on weed suppression has not been studied. Due to the high cost of canola production, knowing the relative importance of these inputs and their contributions to weed competition and final yield could be very beneficial to producers. Producers must optimize their inputs to achieve maximal yield while minimizing input cost and risk. By knowing how or if input benefits such as those

from seed treatments, increased seeding rates and hybrid technology relate or overlap, producers may be able to make better decisions to get the most out of their investment.

This study has three main objectives. The first is to evaluate Helix as a representative of a new generation of seed treatments relative to the current industry standard seed treatment for canola. Secondly, to examine the effect of seed treatments on canola competition against barley, and the third is to distinguish the relative contribution of each input (seed treatment, hybrid canola, increased seeding rate) to canola's weed suppression ability and to canola yield.

Materials and Methods

Field Experiments

Experiments were conducted at two sites during 1999 and three sites in 2000 in the Aspen Parkland Ecoregion near Brandon Manitoba. In 1999 sites were located on a sandy loam of the Carol series (sandy loam) and Assiniboine clay (clay). In 2000 sites were on a sandy loam of the Carol series, Assinaboine clay (clay), and clay loam of the Newdale series (clay loam). Prior to this research all sites, with the exception of the 2000 clay site, were in zero-till production. The 2000 clay site had been tilled once in the fall and twice in the spring prior to seeding. Wheat and flax were previously grown on the sandy loam site in 1999 and 2000, respectively. Barley was the previous crop at the clay and clay loam sites.

Experimental Design

The field experiments were in a randomized complete block (RCB) with treatments arranged factorially. Experimental factors were canola cultivar, the presence

or absence of weeds, seeding rate, and seed treatment (Table 1). The cultivars were Invigor 2273, a hybrid and Exceed, an open pollinated variety. Both are resistant to the herbicide glufosinate, and have similar disease resistance and days to maturity (Seed Manitoba, 2000). Virden barley provided weed competition and was seeded at target density of 20 plants m^{-2}. Based on work done by O'Donovan (1988), volunteer barley density was chosen to attain yield loss of 20%, 16%, 12% and 8% for each target canola density, respectively. A new generation seed treatment (thiamethoxam, difenoconazole, fludioxonil & metalaxyl-M) was compared to standard seed treatments (lindane, carbathiin & thiram) ± terbufos and bare seed. Plots were 2m x 7m, and sites were blocked according to topographical change with each block being a replicate.

Table 1: Summary of experimental factors

Factor	Details
Cultivar	1. Hybrid (Invigor 2273) 2. Open Pollinated (Exceed)
Seeding Rate	Target canola density 1. 37.5 plants m^{-2} 2. 75 plants m^{-2} 3. 150 plants m^{-2} 4. 300 plants m^{-2}
Seed Treatment	5. Nontreated (Control) 6. difenoconazole, fludioxonil, metalaxyl-M & thiamethoxam (Helix) 7. carbathiin, thiram & lindane (Vitavax RS) 8. carbathiin, thiram, lindane & terbufos (Vitavax RS + Counter)
Weeds	1. Weeds removed with herbicides 2. Volunteer barley at 20 plants m^{-2} and other weeds removed with herbicides

Seed Treatment & Packaging

Germination and 1000 seed weight tests were performed on both cultivars prior to the treatment of seed. Seed was treated with either a mixture of thiamethoxam, difenoconazole, fludioxonil, & matalaxyl-M or a mixture of lindane, carbathiin, & thiram using a Hege 11 seed treater. Cultivars were treated separately, mixed for 30 second periods during which chemical was added using a syringe at the recommended rates for each chemical (Table 2).

Table 2: The amount of seed treated and rates used

Seed Treatment	Rate (L 25kg seed^{-1})	Invigor (kg)	Chemical added (mL)	Exceed (kg)	Chemical added (mL)
Helix	0.38	1.15	17.25	0.60	9.00
Vitavax RS	0.56	2.20	49.00	1.80	40.00

Samples were then placed into plastic trays and left to dry. After drying 1000 seed weights were adjusted to account for the addition of seed treatment prior to packaging. Seed was weighed and packaged into individual envelopes corresponding the desired seeding rate cultivar, and seed treatment, adjusted for germination and 1000 seed weight. Terbufos was added on a 50:50 seed mass to terbufos mass basis to the appropriate envelopes just prior to seeding.

Example:

$$\frac{\text{(Target Density plants or seeds m}^{-2} * \text{plot size m}^2)}{\text{Germination \%} * \text{(1000 seed wt g / 1000 seeds)}}$$

$$\frac{\text{(75 seeds m}^{-2} * \text{19 m}^2)}{\text{84\% Germination} * \text{3.8g/1000 seeds}}$$

$$= 6.45 \text{ g seed/plot}$$

Seeding & Fertility

Seeding was done using a no-till seeder with minimal disturbance hoe openers. Canola and volunteer barley were seeded in the same row to a depth of approximately 1.5cm. All fertilizer was added using the zero-max system. Urea (46-0-0-0) was mid-

row disk banded, ammonium phosphate (12-51-0-0) was applied with the seed, and ammonium sulfate (21-0-0-24) was broadcast prior to seeding using a Velmar applicator (Table 3). Seeder and Velmar were calibrated each spring. In 1999 the sandy loam site was seeded on June 2nd and the clay site on June 3rd. In 2000 seeding at the sandy loam, clay, and clay loam sites commenced on May 15th , 17th, and 19th, respectively.

Table 3: Fertilizer type and rate of application

Fertilizer	Rate	Actual			
		Nitrogen	Phosphorus	Potassium	Sulfur
	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)
46-0-0-0	100	46	0	0	0
12-51-0-0	50	6	26	0	0
21-0-0-24	84	18	0	0	20
Total		70	26	0	20

Weed Control

Herbicides were applied to ensure that weed-free plots were free of weeds and that weedy plots only contained barley (Table 4). Solution volume and pressure were 111 L/ha and 275 kPa pressure, respectively.

Table 4: List of herbicides applied during the study.

Common name	Year	Location	Rate(s) g product ha^{-1}	g ai ha^{-1}	Method
Ethametsulfuron-methyl[1]	1999	Sandy loam	20	14	Tractor
	2000	Sandy loam	20	14	
	2000	Clay	20	14	
	2000	Clay loam	20	14	
Quinclorac	2000	Sandy loam	168	126	Tractor
			mL product ha^{-1}	g ai ha^{-1}	
Glyphosate[2]	1999	Sandy loam	1235	445	Tractor
	1999	Clay	1235	445	
	2000	Sandy loam	1235	445	
	2000	Clay loam	1235	445	
Clopyralid[3]	2000	Sandy loam	420	151.2	Tractor
	2000	Clay	420	151.2	
	2000	Clay loam	420	151.2	
Diclofop-methyl[3]	2000	Sandy loam	2800	795.2	Tractor
	2000	Clay	2800	795.2	
	2000	Clay loam	2800	795.2	
Glufosinate[4]	1999	Sandy loam	2720	408	Backpack
	1999	Clay	2720	408	
	2000	Sandy loam	2720	408	
	2000	Clay	2720	408	
	2000	Clay loam	2720	408	
Clethodim[4]	2000	Sandy loam	200	48	Backpack
	2000	Clay	200	48	
	2000	Clay loam	200	48	

[1]The surfactant Agral 90 accompanied ethalmetsulfuron-methyl at 0.2L surfactant per 100L spray solution.
[2]Glyphosate was used as a pre-seed burn-off.
[3]Clopyralid and diclofop-methyl were applied as a tank mix.
[4]Glufosinate and clethodim were applied as a tank mix.

Damage caused by Flea Beetles and Plant Establishment

Ratings for damage caused by flea beetles and plant establishment counts were performed on the dates listed in table 5. Twenty plants for each plot were randomly rated for damage caused by flea beetles during the cotyledon to first leaf stage on a scale of 0-

10 with 0 being undamaged and 10 completely destroyed (Bodnaryk & Lamb, 1991). To determine relative plant establishment, two half meter row samples of canola were counted at opposite corners of each plot, excluding outside rows.

Table 5: Sampling schedule for plant establishment and ratings for damage caused by flea beetles.

Measurement	Sandy Loam		Clay		Clay Loam
	1999	2000	1999	2000	2000
Plant Establishment Counts	06-29[++] (4-5 leaf stage)	06-08 (2-3 leaf stage)	06-24 (3-4 leaf stage)	06-09 (1-2 leaf stage)	06-09 (2-3 leaf stage)
Ratings for damage from flea beetles	06-13	05-30	06-16	06-05	06-15

[++]dates are arranged by month, followed by day.

Canola Growth (Biomass & Canopy Closure)

Canola ground cover was documented using digital image analysis. Due to time constraints, only plots with target densities of 75 and 150 plants m^{-2} for both canola cultivars were sampled. Since the software could not distinguish between species, only pictures of weed free plots were taken. Digital images had a resolution of 1024 * 768 pixels and were taken from a tripod positioned 1.2m directly above each plot. Pictures were taken every week for four weeks. Images were analyzed for green area using Image X software developed by Lachkdar Lamari, at the University of Manitoba, department of plant science.

Canola biomass was taken only from plots with target density of 150 and 300 plants m^{-2}. Ten plants were removed from each plot, placed in paper bags, dried at 70°C down to 12% moisture, then weighed. To eliminate choice bias, five plants in the second row from the plot edge were selected at opposite plot corners, one meter from the end of the plot. The following three samplings were done in a similar fashion, taken 2, 4 and 6m from the end of the plot. In 1999, biomass was sampled at 14, 21, 28 and 35 days after

emergence (DAE). In 2000, plants were sampled at 21, 35, 49 and 63 DAE. In 1999, volunteer barley biomass was taken at 51 DAE and 63 DAE for the sandy loam site and the clay site, respectively. In 2000, volunteer barley biomass was sampled at 63 DAE for all locations. Volunteer barley was sampled from a half meter of row, half a meter from the end of the plot and two rows in from the side, and from opposite corners of each plot. Volunteer barley was cut off at ground level and placed in paper bags and dried at 70°C down to 12% moisture and weighed.

Canola Stem Disease

Twenty plants were randomly removed from each plot and rated on a yes/no basis for the occurrence of blackleg and sclerotinia.[1] In 1999 only the basal portion of each plant was rated for each disease as disease infestation on the upper portion of plants was relatively low. Due to hail damage in 2000, there was considerably more sclerotinia and blackleg on the upper portion of plants, so it was rated as well.

Harvest & Seed Cleaning

All plots at a site were swathed at the same time when the maturity level of the low density plots was suitable but before the high density plots began to shatter. The middle six rows of each plot were swathed leaving a stubble length of approximately 20cm. Swaths were left to cure 7-10 days depending on weather conditions, then harvested into cloth bags using a Hege plot harvester. Seed was dried in an air dryer before samples were sieved to separate the volunteer barley from the canola. Canola was cleaned with a Carter Day dockage tester using recommended protocols to remove any

[1] Personal communication with Dr. Debbie McLaren from Agriculture and Agri-Food Canada.

chaff and volunteer barley followed by cleaning with a Clipper seed cleaner. Cleaned samples of canola and volunteer barley were weighed.

Data Analysis

ANOVA

All data was first converted to meaningful units (kg/ha, g/plant) and analyzed using the UNIVARIATE procedure in SAS to evaluate normality. To improve normality, some data was analyzed in log base 10 format. ANOVA tables were created using the GLM procedure in SAS and data for all sites were combined and tested for interaction with site year. Due to different interactions among site years, sites were analyzed separately.

To estimate relative influence of factors (cultivar, seeding rate, seed treatment, presence/absence of weeds) on dependent variables (plant establishment, damage from flea beetles, canola yield, and dockage), a ratio of the factor sum of squares and total sum of squares was calculated (Therrien, 2000). Contrasts were used to examine the effect of seed treatment on cotyledon damage caused by flea beetles. Least significant difference (LSD) tests were used for testing significance between seed treatments, cultivars, and weedy and weed-free treatments, with p-values in each case set at the 0.05 level of significance.

Non Linear Line Fitting

Non linear regression was used to determine the relationship between the continuous variable, seeding rate, and other experimental factors (cultivar, seed treatment, presence/absence of weeds). Linear regression related canola biomass accumulation and canola ground cover to growing degree days. Prior to regression,

orthogonal contrasts (PROC GLM) using SAS (SAS Institute Inc) determined the nature of each relationship (linear, quadratic, or cubic). Data were fitted to models using a derivative-free nonlinear regression procedure (PROC NLIN) using SAS. A linear model was employed for canola ground cover :

$$y = mx$$

where y = dependent variable (ground cover), m = slope, and x = accumulated growing degree days. A linear model was also used for canola biomass accumulation:

$$y = mx+b$$

Where y = dependent variable (canola biomass), m = slope, x = accumulated growing degree days, and b = y-intercept. A rectangular hyperbola model (Coursens, 1985; O'Donovan et al. 1988) was used for canola yield:

$$Yc = id/(1+id/a)$$

Where Yc = canola yield, i = initial slope, d = canola density, and a = asymptote. A rectangular hyperbola model was used for volunteer barley biomass and dockage (Eq.4).

$$Yb = I / (1+sd)$$

Where Yb = volunteer barley dockage or biomass, I = y-intercept, and d = canola density.

Regression used means (Gomez & Gomez, 1984) rather than raw data for canola biomass accumulation and canola ground cover. For barley biomass and dockage, raw data was regressed against canola density. A significant blocking effect occurred for canola yield so data was adjusted to remove any variance due to blocking.[2] This involved

[2] Personal conversation with Dr. Crow from the University of Manitoba.

adjusting each data point per block according to the difference between the block mean and overall mean (table 6).

Table 6: Sample of canola yield replicate adjustment to eliminate blocking variance for non-linear regression.

Block	Replication Mean Canola Yield (kg/ha)	Overall Mean – Block Mean	Adjustment factor For each data point
1	1308.6	150.9	Add 150.9
2	1430.1	29.4	Add 29.4
3	1557.5	-98.0	Subtract 98.0
4	1541.8	-82.3	Subtract 82.3
Overall Mean	1459.5		

Model regression first included all significant factors (cultivar, weeds, seed treatment) from ANOVA and tested for convergence. In the case of canola yield, seed treatment did not converge so it was excluded from the nonlinear regression analysis. More inclusive models were tested against models with combined factors using the lack-of-fit F-test (Seefeldt et al, 1995):

$$F = (SS_e^{II} - SS_e^{I})/(DF_e^{II} - DF_e^{I})/(SS_e^{I}/DF_e^{I})$$
$$\sim F(DF_e^{II} - DF_e^{I}, DF_e^{I})$$

where SSe is error sum of squares, and DFe is degree of fredom and F is approximately F-distributed if model I can be reduced to model II. When the model could no longer be reduced based on factor significance, models were compared systematically to see if coefficients (asymptotes, slopes, y-intercepts) differed, again using the lack-of-fit F-test. Coefficients of determination (R^2) were calculated from the residual sum of squares value from the SAS output (Kvalseth, 1985). Only one residual sum of squares value was provided by SAS, despite parameters for several function being estimated at the same time (Seefeldt et al., 1995).

Greenhouse Experiment

The experiment was conducted during December, 2000 and January, 2001, using a target neighbor design (Gibson et al., 1999; Keddy et al., 2000). Canola acted as the phytometer, surrounded by three barley with all plants spaced 4.5cm apart. Seed treatments were a mixture of 1) thiamethoxam, difenoxinol, fluidoxonil, and metalaxyl-M, 2) lindane, carbathiin and thiram, and 3) bare seed. Plants were allowed to grow for 30 days before they were harvested. The experiment was conducted twice and treatments were replicated a total of 15 times. To reduce size variability, seed was screened before being treated. Seed was treated by shaking seed and chemical (label rate) in glass jars for 30 seconds, then dried 4 hours before planting. Bare seed was subjected to similar treatment without the addition of chemical. Greenhouse temperature was a constant 20°C. Seeding depth was 1cm and plants were 4.5cm apart in a sandy loam soil. Five grams of slow release 14-14-14 fertilizer were added prior to planting for the first run. Nine grams were added to each pot for the second run of the experiment due to a small number of plants showing nitrogen deficiency during the previous run. Forty milliliters of 0.28M ammonium sulfate solution were added 3 times (one week interval) during watering to eliminate any possible sulfur deficiencies. Watering occurred regularly to ensure water content was near field capacity. Emergence was monitored and any unevenly emerged pots removed. Harvesting of above ground biomass commenced after 30 days and samples were dried at 60°C for 72 hours.

Data were converted to a competition ratio (Eq.6) prior to analysis, with higher values suggesting greater competitiveness:

Competition Ratio = Canola Biomass (g) / Barley Biomss (g)

Data was then subjected to Bartlett's test for the homogeneity of variance and the runs were combined. Combined data were subjected to ANOVA and differences between treatments assessed using a LSD test ($p<0.05$).

Results and Discussion

Plant Establishment

Plant establishment counts determined if target canola and barley densities were achieved. Canola establishment was used as an indirect measurement of soil-borne pathogen activity in the soil. Greater levels of pathogenicity would be shown by greater differences between target and actual densities.

Seeding rate had the greatest impact on plant establishment relative to cultivar and seed treatment, with contributions to total variance ranging from 72-80% for seeding rate, 0.2-2.3% for cultivar and 0.1-2.0% for seed treatment (Table 7). Target densities were not always achieved with the difference between target and actual densities increasing as target density increased (Figure 1). Cultivar and seed treatment did not influence establishment in all cases. For instance, the Invigor variety established closer to target densities than the Exceed variety only for the target density of 75 plants m^{-2} at the 1999 clay site, 300 plants m^{-2} at the 2000 sandy loam site, and 37.5, 75, and 300 plants m^{-2} at the 2000 clay site (Table 8). The effect of seed treatment was also sporadic, with different seed treatments positively affecting emergence compared to bare seed depending on location (Table 9).

Actual barley densities were uniform within sites and close to the target density, ranging from 18-28 plants m^{-2} (Table 10). Therefore, volunteer weed competition was uniform within sites and similar between sites.

Table 10 Barley Establishment: for each site during 1999 and 2000 (Target: 20 plants m^{-2})

Year	Site	Average (pl/m^2)	Std Error
1999	Clay	26.45	1.00
1999	Sandy Loam	21.21	0.78
2000	Sandy Loam	19.18	0.68
2000	Clay	18.16	0.59
2000	Clay Loam	28.09	1.27

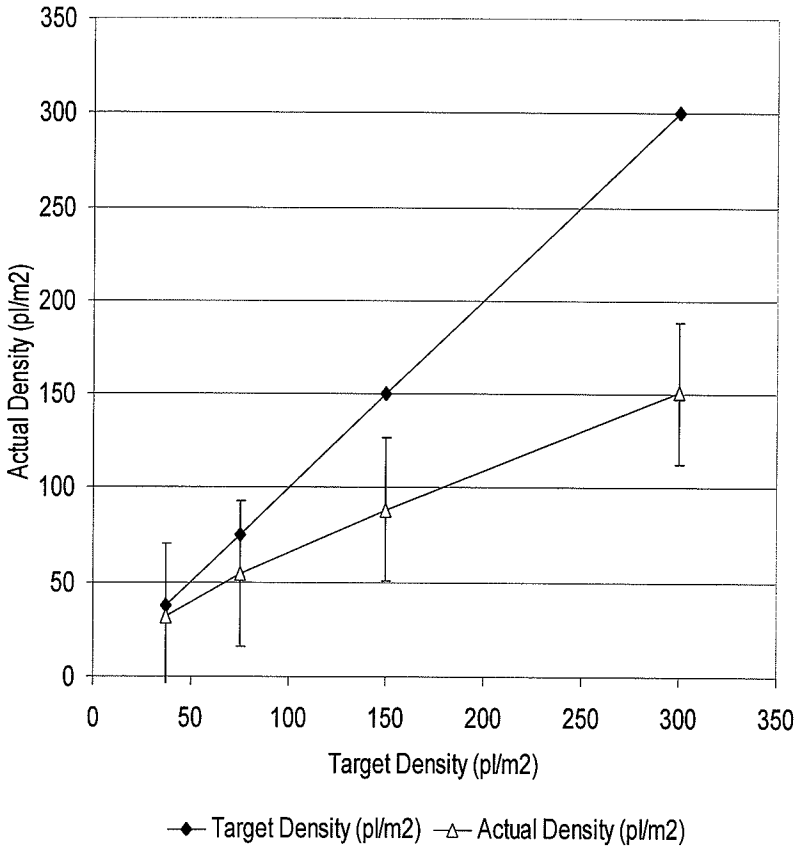


Figure 1: Canola establishment for each target density averaged over all sites

Table 7: Contribution of cultivar, the presence/absence of weeds, seeding rate, and seed treatment to total variation for canola establishment calculated from ANOVA[a].

Source	1999 Clay			1999 Sandy Loam			2000 Sandy Loam			2000 Clay			2000 Clay Loam		
	df	% total	Signif.[b]	df	% total	Signif.	df	% total	Signif.	df	% total	Signif.	df	% total	Signif.
Error	189	17.4	-	189	12.2	-	189	17.2	-	189	10.6	-	189	16.0	-
Replication	3	2.3	***	3	1.0	NS	3	0.6	NS	3	0.5	*	3	0.1	NS
Cultivar	1	0.9	**	1	1.0	**	1	2.9	***	1	2.3	***	1	0.2	NS
Presence/Absence of Weeds	1	0.5	*	1	<0.1	NS	1	0.3	NS	1	0.1	NS	1	<0.1	NS
Seeding Rate	3	73.9	***	3	80.0	***	3	72.3	***	3	80.4	***	3	77.2	***
Seed Treatment	3	0.1	NS	3	2	***	3	1.2	**	3	1.0	***	3	1.1	**

[a]Data presented only for main treatment and not interactions.
[b]Signif. = Significance
*,**,***Significant at p = 0.05, p = 0.01, and p = 0.001, respectively; NS, not significant

Table 8: The effect of cultivar on canola establishment.

Year	Site	Target Canola Density (pl m^{-2})	Cultivar	Actual Density (pl m^{-2})	Std Error	Pr > |T| H0:*
1999	Clay	75	Invigor	59.53	3.14	0.0017
1999	Clay	75	Exceed	46.88	2.42	
2000	Sandy Loam	300	Invigor	164.84	5.08	0.0016
2000	Sandy Loam	300	Exceed	134.53	7.91	
2000	Clay	37.5	Invigor	35.16	2.15	0.0003
2000	Clay	37.5	Exceed	24.53	1.62	
2000	Clay	75	Invigor	60.78	2.53	0.0005
2000	Clay	75	Exceed	45.94	3.19	
2000	Clay	300	Invigor	164.53	5.16	0.0002
2000	Clay	300	Exceed	138.28	5.87	

* t-tests were used to compare cultivars at each site.

Table 9: Effect of seed treatment on canola establishment.

Year	Site	Target Canola Density (pl m^{-2})	Seed Treatment	Actual Density (pl m^{-2})	Std Error	LSD ($p<0.05$)/location
1999	Sandy Loam	150	Helix	106.25	5.35	a
1999	Sandy Loam	150	VV	112.81	4.06	a
1999	Sandy Loam	150	VVC	93.44	4.65	b
1999	Sandy Loam	150	none	83.75	4.88	b
1999	Sandy Loam	300	Helix	175.00	6.66	a
1999	Sandy Loam	300	VV	170.00	7.12	ab
1999	Sandy Loam	300	VVC	152.50	7.75	bc
1999	Sandy Loam	300	none	143.44	7.89	c
2000	Clay	300	Helix	145.94	7.12	b
2000	Clay	300	VV	141.25	9.12	b
2000	Clay	300	VVC	178.44	7.02	a
2000	Clay	300	none	140.00	7.00	b

Differences between target and actual densities demonstrated that as seeding rate increased the effect of intra-specific competition was greater and self-thinning was greater. Increasing seeding rate can also magnify the probability of soil-borne disease infection (Gilligan, 2000). When host plants are closer together the secondary infection process accelerates (Bailey, 2000); however, host growth rate also affects fungal infection (Gilligan, 1987), with plants becoming less susceptible as they get older. Consequently, the difference between actual and target densities should have increased when seed was untreated or when the Exceed variety was used, but this did not always occur.

Manitoba typically has low levels of damping off pathogens affecting canola (Platford et al, 1999), and the patchiness of soil borne disease tends to increase as overall disease levels decrease (Gilligan, 1987). Neither seed treatment or cultivar consistently increased emergence in this study. The fact that seed treatment had a positive effect on emergence in some cases comfirms their fungicidal activity (Kataria et al, 1990, 1993; Dahmen et al, 1992; Mathieson, 1991; Davis et al, 1997; Cabras et al, 1997), and greater emergence for the Invigor variety supports Gilligan=s suggestion (1987) that plants with higher growth rates may elude infection, but since disease levels were not measured these remarks cannot be made with certainty. What is certain is that using either a seed treatment or hybrid seed did not have a major impact on canola stand development in this study, possibly due to low, patchy levels of damping off disease affecting canola.

Damage Caused by Flea Beetles

Visual cotyledon damage ratings were done to provide information on the protective properties of seed treatment, saturation potential of seeding rate, and damage

evasion potential of cultivars. Insecticides in seed treatments protect seedlings from damage caused by flea beetles. By saturating flea beetles with food, higher seeding rates may reduce flea beetle damage on a per plant basis. Hybrid canola may evade flea beetle damage by rapid growth through the early and most susceptible stages of development, causing flea beetles to proceed to younger targets.

Seed treatment had a greater impact on reducing flea beetle damage compared to cultivar and seeding rate. In 1999, seed treatment was responsible for 64-67% of the total variance relative to 0-1% for both cultivar and seeding rate (Table 11). Furthermore, in 2000 seed treatment accounted for 37-64% of the total variance with cultivar contributing 0-6% and seeding rate 0-3%. In all site years, thiamethoxam provided performance similar to that of lindane and lindane plus terbufos and better performance than the untreated control (Table 12).

The hybrid variety Invigor sustained more damage than the open pollinated variety Exceed only at the sandy loam and clay sites in 2000, especially when no seed treatment was used (Figures 2-6). For both cultivars, cotyledon damage per plant caused by flea beetles increased as seeding rate increased when no seed treatment was used. The opposite occurred when seed treatment was used, with damage decreasing as seeding rate increased.

Table 11: Contribution of Cultivar, the presence/absence of weeds, seeding rate, and seed treatment to total variation for damage caused by flea beetles calculated from ANOVA[a].

	1999 Clay			1999 Sandy Loam			2000 Sandy Loam			2000 Clay			2000 Clay Loam		
Source	df	% total	Signif.[b]	df	% total	Signif.	df	% total	Signif.	df	% total	Signif.	df	% total	Signif.
Error	189	24.0	-	189	21.1	-	189	19.4	-	189	19.7	-	189	27.6	-
Replication	3	4.6	***	3	0.2	NS	3	1.6	**	3	1.1	*	3	10.5	***
Cultivar	1	0.1	NS	1	0.1	NS	1	4.1	***	1	5.6	***	1	0.2	NS
Presence/Absence of Weeds	1	0.2	NS	1	<0.1	NS	1	0.1	NS	1	<0.1	NS	1	<0.1	NS
Seeding Rate	3	0.6	NS	3	<0.1	NS	3	2.7	***	3	0.4	NS	3	0.4	NS
Seed Treatment	3	64.1	***	3	67.2	***	3	41.3	***	3	63.8	***	3	37.3	***

[a]Data presented only for main treatment and not interactions.
[b]Signif. = Significance
*,**,***Significant at p = 0.05, p = 0.01, and p = 0.001, respectively; NS, not significant

Table 12: Effect of seed treatment on cotyledon damage caused by flea beetles for Invigor canola and Exceed canola at different target densities.

				p-values by target density [a]			
Year	Site	Cultivar	Contrast	37.5	75	150	300
1999	Clay	Invigor	None vs Seed Treatment	0.0001	0.0001	0.0001	0.0001
			Helix[b] vs Industry Standard[c]	0.0021	0.0245	0.1519	0.3541
			Addition of Counter[d] to Vitavax RS[e]	0.8568	0.9892	0.9194	0.8289
1999	Clay	Exceed	None vs Seed Treatment	0.0001	0.0001	0.0001	0.0001
			Helix vs Industry Standard	0.5883	0.0183	0.2607	0.5178
			Addition of Counter to Vitavax RS	0.1986	0.1449	0.0572	0.3199
1999	Sandy Loam	Invigor	None vs Seed Treatment	0.0001	0.0001	0.0001	0.0001
			Helix vs Industry Standard	0.9175	0.0071	0.0475	0.5707
			Addition of Counter to Vitavax RS	0.2975	0.0216	0.4853	0.1569
1999	Sandy Loam	Exceed	None vs Seed Treatment	0.0012	0.0001	0.0001	0.0001
			Helix vs Industry Standard	0.7201	0.2417	0.1788	0.4090
			Addition of Counter to Vitavax RS	0.3408	0.5570	0.2798	0.8714
2000	Sandy Loam	Invigor	None vs Seed Treatment	0.0108	0.0001	0.0001	0.0001
			Helix vs Industry Standard	0.3268	0.1730	0.0004	0.0001
			Addition of Counter to Vitavax RS	0.6276	0.1502	0.4585	0.0998
2000	Sand Loam	Exceed	None vs Seed Treatment	0.0694	0.0006	0.0002	0.0001
			Helix vs Industry Standard	0.6890	0.0238	0.0019	0.0341
			Addition of Counter to Vitavax RS	0.3669	0.2577	0.3931	0.4761
2000	Clay	Invigor	None vs Seed Treatment	0.0001	0.0001	0.0001	0.0001
			Helix vs Industry Standard	0.2257	0.5073	0.9114	0.1070
			Addition of Counter to Vitavax RS	0.5319	0.6876	0.0390	0.8784
2000	Clay	Exceed	None vs Seed Treatment	0.0001	0.0001	0.0001	0.0001
			Helix vs Industry Standard	0.4220	0.8663	0.0081	0.2721
			Addition of Counter to Vitavax RS	0.7110	0.3827	0.7639	0.6366
2000	Clay Loam	Invigor	None vs Seed Treatment	0.0443	0.0001	0.0001	0.0001
			Helix vs Industry Standard	0.5661	0.9034	0.0238	0.0587
			Addition of Counter to Vitavax RS	0.3762	0.2304	0.2581	0.1693
2000	Clay Loam	Exceed	None vs Seed Treatment	0.1714	0.0297	0.0004	0.0003
			Helix vs Industry Standard	0.9112	0.1530	0.2902	0.0266
			Addition of Counter to Vitavax RS	0.3146	0.7223	0.5137	0.8289

[a] Contrasts performed on $\log_{10}$ transformed data.
[b] Helix = thiamethoxam, difenoconazole, fludioxonil, & metalaxyl-M
[c] The industry standard is the average damage for Vitavax RS and Vitavax RS & Counter
[d] Counter = terbufos
[e] Vitavax RS = lindane, carbathiin, & thiram

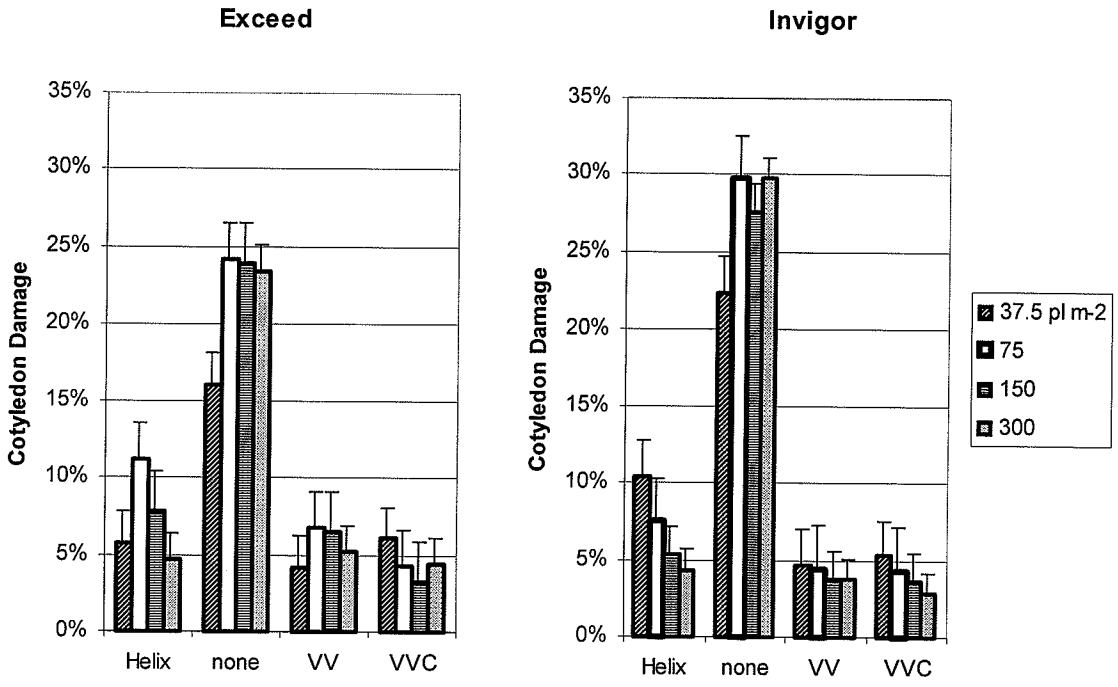


Figure 2: The percentage of canola cotyledons damaged by flea beetle feeding for two cultivars using seed treatments (Helix, non-treated(none), Vitavax RS (VV), Vitavax RS & Counter (VVC)) at four different target canola densities at the 1999 clay site.
Helix = thiamethoxam, difenoconazole, fluidioxonil, & metalaxyl-M.
Vitavax RS = lindane, carbathiin, & thiram.
Counter = terbufos.

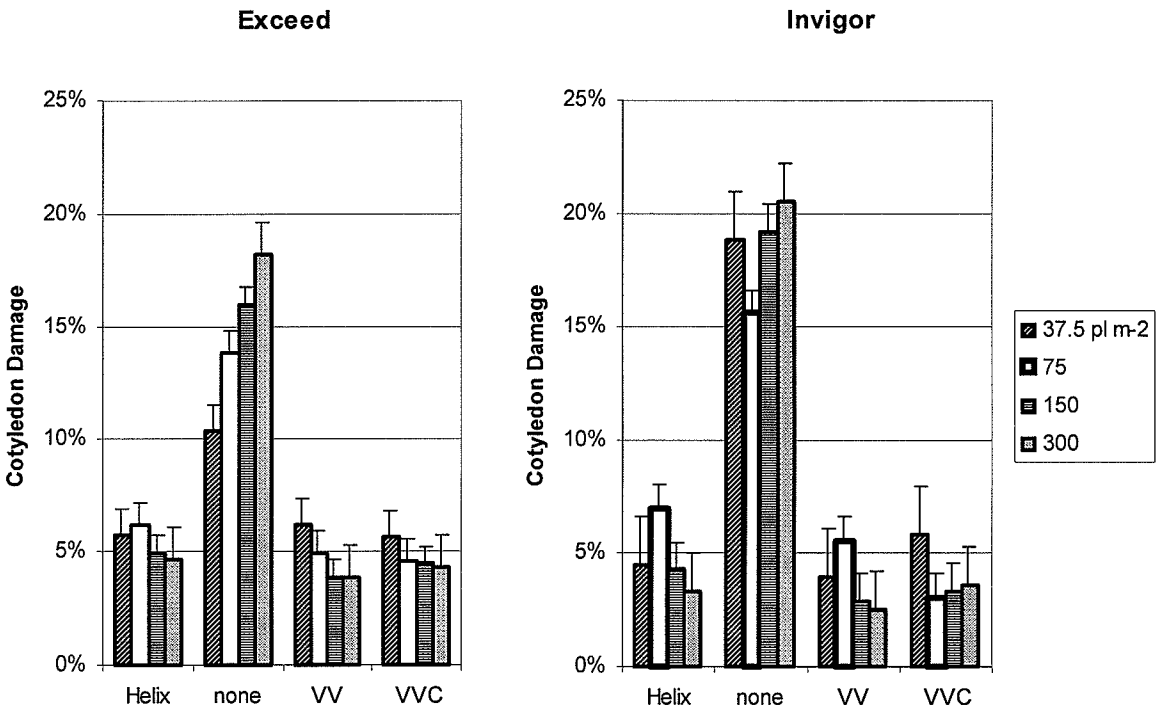


Figure 3: The percentage of canola cotyledons damaged by flea beetle feeding for two cultivars using seed treatments (Helix, non-treated(none), Vitavax RS (VV), Vitavax RS & Counter (VVC)) at four different target canola densities at the 1999 sandy loam site.
Helix = thiamethoxam, difenoconazole, fluidioxonil, & metalaxyl-M.
Vitavax RS = lindane, carbathiin, & thiram.
Counter = terbufos.

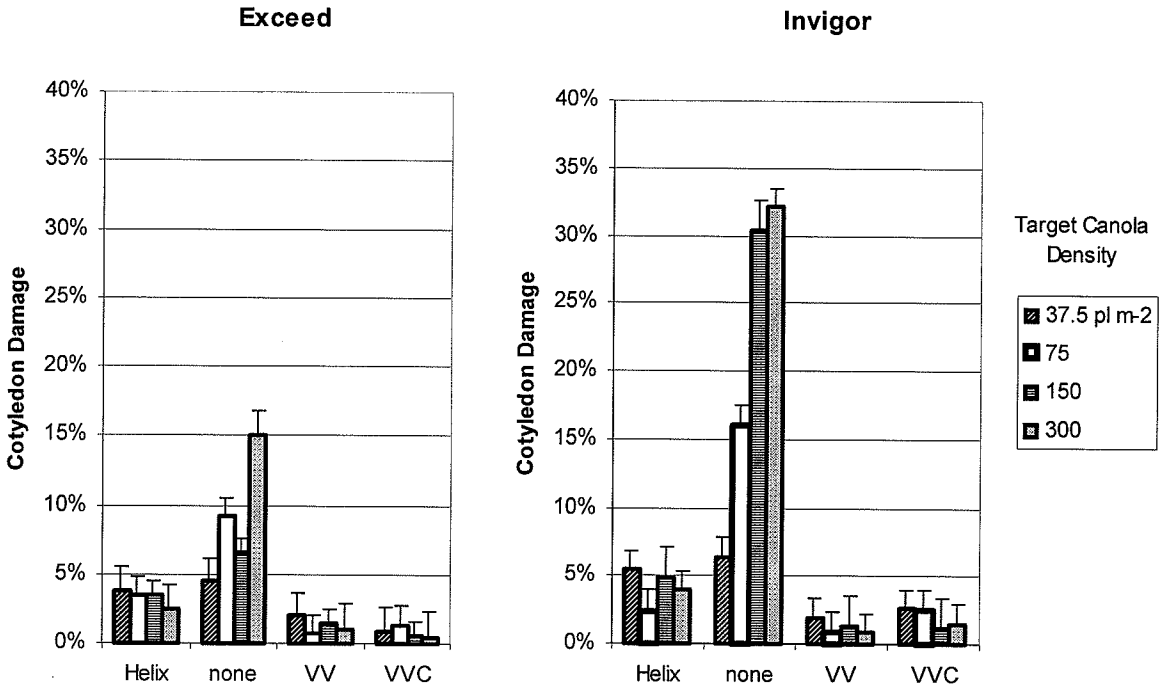


Figure 4: The percentage of canola cotyledons damaged by flea beetle feeding for two cultivars using seed treatments (Helix, non-treated(none), Vitavax RS (VV), Vitavax RS & Counter (VVC)) at four different target canola densities at the 2000 sandy loam site.
Helix = thiamethoxam, difenoconazole, fluidioxonil, & metalaxyl-M.
Vitavax RS = lindane, carbathiin, & thiram.
Counter = terbufos.

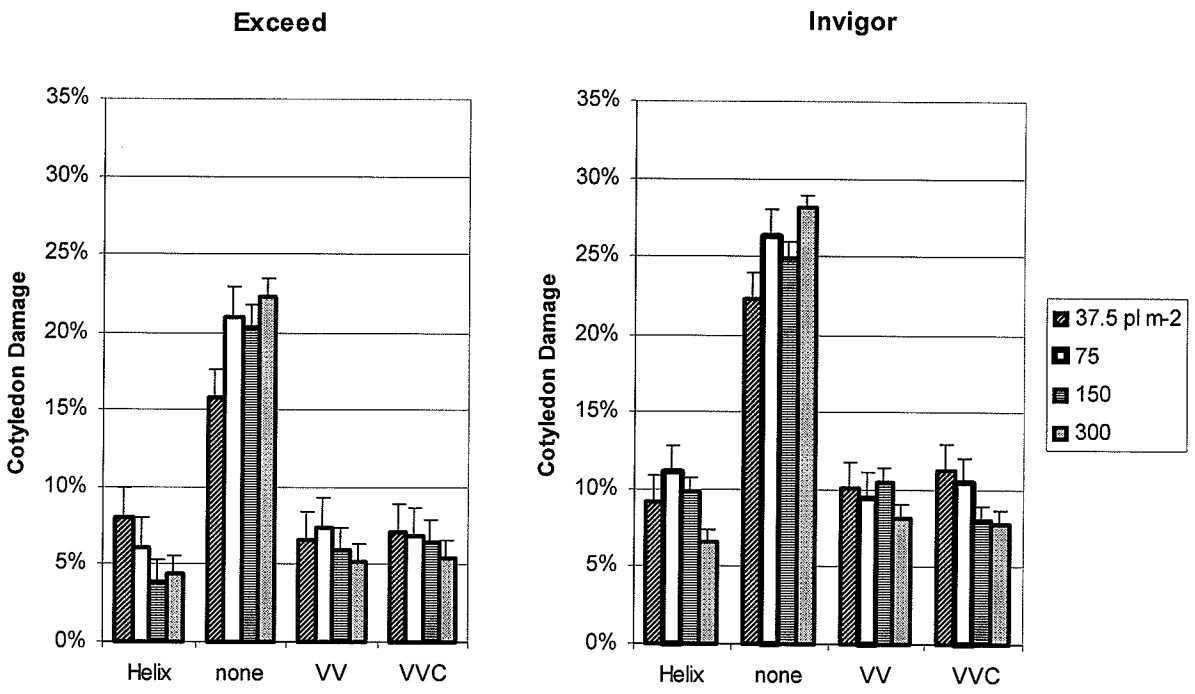


Figure 5: The percentage of canola cotyledons damaged by flea beetle feeding for two cultivars using seed treatments (Helix, non-treated(none), Vitavax RS (VV), Vitavax RS & Counter (VVC)) at four different target densities at the 2000 clay site.
Helix = thiamethoxam, difenoconazole, fluidioxonil, & metalaxyl-M.
Vitavax RS = lindane, carbathiin, & thiram.
Counter = terbufos.

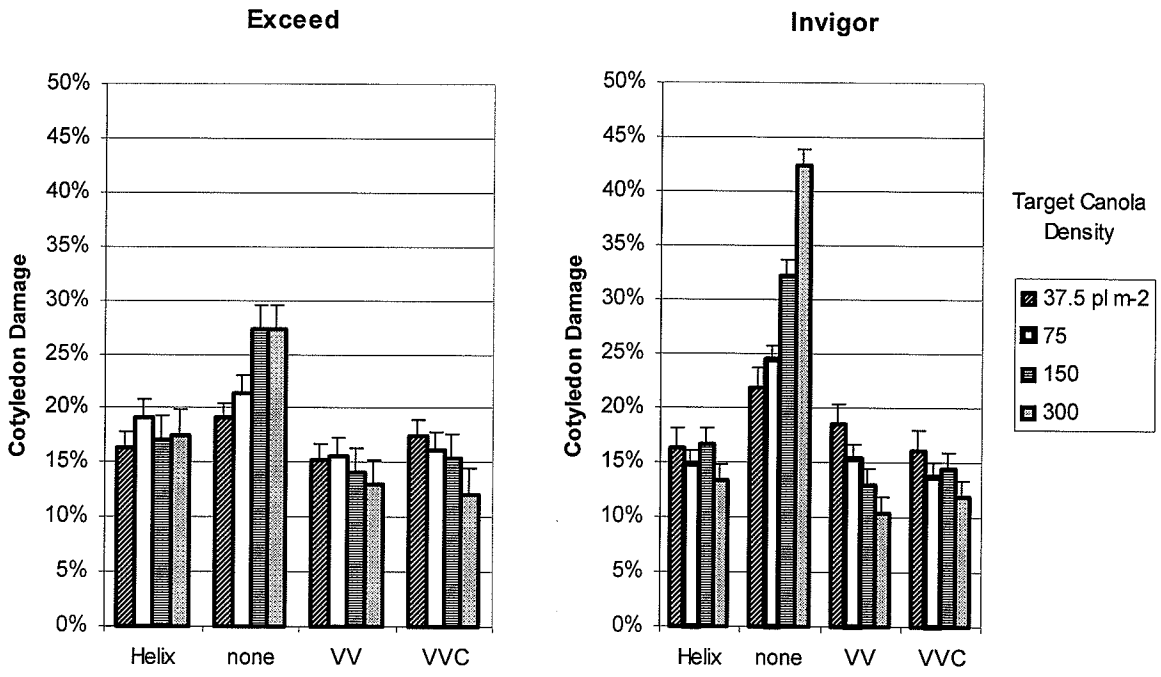


Figure 6: The percentage of canola cotyledons damaged by flea beetle feeding for two cultivars using seed treatments (Helix, non-treated(none), Vitavax RS (VV), Vitavax RS & Counter (VVC)) at four different target densities at the 2000 clay loam site.
Helix = thiamethoxam, difenoconazole, fluidioxonil, & metalaxyl-M.
Vitavax RS = lindane, carbathiin, & thiram.
Counter = terbufos.

Overall, seedlings were protected from flea beetles when seed treatment was used and as a result seed treatment was the most important factor affecting flea beetle damage. Despite potential hybrid vigor, the Invigor variety had more damage than the Exceed variety, with damage increasing as seeding rate increased when no seed treatment was used. Any benefit, in terms of reduced flea beetle damage, due to food saturation from increased seeding rates, or the hybrid variety Invigor evading flea beetle feeding, was relatively small or non-existent compared to the effect of seed treatment.

Using a seed treatment protected seedlings from flea beetles, with thiamethoxam performing similar to lindane and terbufos. All of these insecticides have shown good activity against a variety of insects (Weiss et al., 1991; Westcott, 1985; Szeto et al., 1986; Toba et al., 1985; Mason et al., 2000; Maienfisch et al., 1999) and they performed as expected. What was surprising was the appearance of greater damage when seeding rate was high and seed was untreated. This is contrary to findings by Dorsdall et al. (1999) and may be due to a number of factors including; plot size, the use of only one tillage system, the surrounding crop, and weather.

Small, densely seeded canola plots may have caused predation levels higher than typically experience in field conditions for several reasons. Firstly, Harper (1977) suggests plants have a greater probability of predation when present at higher densities because insects can locate prey easier. Since flea beetles are drawn to prey mainly by chemical stimuli (Thvanainen & Root, 1972), they may be drawn to denser stands in the present study simply because more chemical was emitted. Secondly, the lower abundance of flea beetles in no-till systems has been linked to greater structural and micro-climatic diversity (Milbrath & Weiss, 1995), two characteristics that may have

further protected the lower seeding rates in this experiment. Using two or more tillage systems such as Dorsdall et al (1999) means flea beetles may have been drawn to conventional till plots where seedlings are easier to find and microclimatic conditions are more favorable for existance. Finally, earlier seeding in 2000 meant cooler conditions, which can restrict flea beetle movement and reduce the chance of even distribution through-out the experimental area (Dosdall et al, 1999). Had this experiment been surrounded by a canola crop, all of the effects listed above may have been diluted since individual treatments would not have been as sought out by the flea beetles.

Invigor canola had greater damage from flea beetles than the Exceed variety, supporting the conclusion of Bodnaryk et al. (1994) that hybrids contribute no agronomically useful level of resistance to flea beetles under commercial growing conditions. Similar circumstances responsible for higher seeding rates receiving more damage may also be responsible for cultivar differences because the Invigor variety had greater establishment and plants were larger, possibly aiding prey identification. Even if cultivars were equally damaged, seedlings with higher growth rates during the cotyledon stage have shown improved survival (Lamb et al, 1993). Tolerance is closely associated with seed size (Bodnaryk & Lamb, 1991) suggesting larger seeds produce more vigorous seedlings that are more tolerant to flea beetle feeding; however, Brandt and Lamb (1993) concluded the level of tolerance to feeding damage was species specific and growth-stage specific and was not related to the rates of growth of the species. In th study, yield relationships between treated and untreated plots were similar for both varieties despite the Invigor variety sustaining more damage; however, specific tolerance tests were not

performed so whether the greater level of damage had proportionally more impact on yield is impossible to determine.

Canola and Volunteer Barley Growth

Digital images were used to estimate how quickly the ground was shaded by canola. A crop that covers the ground at a high rate may be better able to capture resources and suppress weed growth. Measurements were done on a population basis and then converted to a per plant basis to eliminate any differences in plant density between plots.

At the population level, cultivar and seeding rate had more influence on ground cover than seed treatment at three of four sites (Table 13). Using a higher seeding rate resulted in an increased rate of ground cover, and Invigor covered the ground faster than Exceed (Figures 7-14). Of the top 8 of 16 treatments for each year in terms of their rate of covering the ground per unite growing degree day, 5-7 were Invigor treatments and 6-7 were seeded to the higher target density (Tables 16-19). One bare seed treatment made the top 8 at each site year, which was the Invigor variety at the high seeding rate. Logic suggests that at the population level the combination of higher seeding rate, Invigor and seed treatment should cover the ground fastest, but there were circumstances when one input seemed to compensate for the other.

On a per plant basis, seeding rate was more important than cultivar and seed treatment, with cultivar only significant at the 2000 clay loam site and seed treatment significant at the 2000 clay site (Table 14). At the 1999 and 2000 sandy loam locations the lower seeding rate covered the ground faster (Figures 15&16), opposite of what

happened when considering the entire population. Since each plot was divided by the number of plants within, the lower rate of cover for the higher seeding rate may be due higher levels of intraspecific competition.

The diminished importance of seed treatment and cultivar when ground cover was calculated on a per plant basis suggest that any benefit from seed treatment or hybrid vigor was due mostly to higher establishment numbers and less likely from protection from flea beetle feeding or hybrid vigor. In terms of ground cover, detrimental effects from flea beetles or poor seedling vigor may be overcome by increasing seeding rate.

Table 13: Contribution of cultivar, the presence/absence of weeds, seeding rate, and seed treatment to total variation for canola ground cover per m^{-2} calculated from ANOVA[a].

	1999 Sandy Loam			2000 Sandy Loam			2000 Clay			2000 Clay Loam		
Source	df	% total	Signif.[b]	df	% total	Signif.	df	% total	Signif.	df	% total	Signif.
Error	231	7.2	-	231	13.6	-	231	9.7	-	231	14.5	-
Replication	3	0.3	*	3	1.2	***	3	0.5	**	3	1.7	***
Growing Degree Days	3	88.3	***	3	73.5	***	3	77.1	***	3	73.4	***
Cultivar	1	0.6	***	1	5.4	***	1	3.8	***	1	4.3	***
Seeding Rate	3	1.8	***	3	2.6	***	3	4.8	***	3	4.0	***
Seed Treatment	3	1.5	***	3	2.7	***	3	3.0	***	3	1.0	**

[a]Data presented only for main treatment and not interactions.
[b]Signif. = Significance
*,**,***Significant at p = 0.05, p = 0.01, and p = 0.001, respectively; NS, not significant

Table 14: Contribution of cultivar, the presence/absence of weeds, seeding rate, and seed treatment to total variation for canola ground cover per plant calculated from ANOVA[a].

	1999 Sandy Loam			2000 Sandy Loam			2000 Clay			2000 Clay Loam		
Source	df	% total	Signif.[b]	df	% total	Signif.	Df	% total	Signif.	Df	% total	Signif.
Error	231	27.2	-	231	35.8	-	231	21.3	-	231	29.8	-
Replication	3	1.9	**	3	0.1	NS	3	0.5	NS	3	3.6	***
Growing Degree Days	3	61.4	***	3	55.5	***	3	68.1	***	3	54.9	***
Cultivar	1	<0.1	NS	1	<0.1	NS	1	0.4	*	1	7.1	***
Seeding Rate	3	5.2	***	3	4.6	***	3	0.3	NS	3	2.5	***
Seed Treatment	3	1.0	*	3	0.5	NS	3	3.4	***	3	0.5	NS

[a]Data presented only for main treatment and not interactions.
[b]Signif. = Significance
*,**,***Significant at p = 0.05, p = 0.01, and p = 0.001, respectively; NS, not significant

Table 15: The effect of cultivar, target planting density, and seed treatment on the rate at which canola covered the ground at the 1999 sandy loam site[a].

Rank	Parameter			Rate of Ground Cover (m^2 GDD^{-1})	Std. Error	R-squared
	Cultivar	Target Density (plant m^{-2})	Seed Treatment			
1	Invigor	150	Helix	0.000917	0.000038	0.969126
2	Invigor	150	Vitavax RS & Counter (VVC)	0.000863	0.000038	
3	Exceed	150	Vitavax RS & Counter (VVC)	0.000860	0.000038	
4	Exceed	150	Helix	0.000821	0.000038	
5	Exceed	150	Vitavax RS (VV)	0.000815	0.000038	
6	Invigor	150	None	0.000794	0.000038	
7	Invigor	150	Vitavax RS (VV)	0.000789	0.000038	
8	Invigor	75	Vitavax RS & Counter (VVC)	0.000786	0.000038	
9	Invigor	75	Helix	0.000759	0.000038	
10	Invigor	75	Vitavax RS (VV)	0.000715	0.000038	
11	Exceed	75	Vitavax RS & Counter (VVC)	0.000702	0.000038	
12	Exceed	75	Helix	0.000653	0.000038	
13	Invigor	75	None	0.000647	0.000038	
14	Exceed	150	None	0.000635	0.000038	
15	Exceed	75	Vitavax RS (VV)	0.000625	0.000038	
16	Exceed	75	None	0.000507	0.000038	

[a] Data was $\log_{10}$ converted prior to analysis.

Table 16: The effect of cultivar, target density, and seed treatment on the rate at which canola covered the ground at the 2000 sandy loam site[a].

Rank	Parameter			Rate of Ground Cover (m^2 GDD^{-1})	Std. Error	R-squared
	Cultivar	Target Density (plant m^{-2})	Seed Treatment			
1	Invigor	150	Vitavax RS (VV)	0.00098	0.000059	0.93
2	Invigor	150	Helix	0.00097	0.000059	
3	Invigor	150	Vitavax RS & Counter (VVC)	0.00089	0.000059	
4	Invigor	75	Helix	0.00076	0.000059	
5	Exceed	150	Vitavax RS (VV)	0.00076	0.000059	
6	Invigor	150	None	0.00072	0.000059	
7	Invigor	75	Vitavax RS (VV)	0.00072	0.000059	
8	Exceed	150	Vitavax RS & Counter (VVC)	0.00064	0.000059	
9	Invigor	75	Vitavax RS & Counter (VVC)	0.00063	0.000059	
10	Invigor	75	None	0.00061	0.000059	
11	Exceed	150	Helix	0.00059	0.000059	
12	Exceed	75	Vitavax RS (VV)	0.00059	0.000059	
13	Exceed	75	Helix	0.00053	0.000059	
14	Exceed	150	None	0.00052	0.000059	
15	Exceed	75	Vitavax RS & Counter (VVC)	0.00042	0.000059	
16	Exceed	75	None	0.00034	0.000059	

[a] Data was $\log_{10}$ converted prior to analysis.

Table 17: The effect of cultivar, target planting density, and seed treatment on the rate at which canola covered the ground at the 2000 clay site[a].

Rank	Parameter			Rate of Ground Cover (m^2 GDD^{-1})	Std. Error	R-squared
	Cultivar	Target Density (plant m^{-2})	Seed Treatment			
1	Invigor	150	Helix	0.000821	0.000032	0.96
2	Invigor	150	Vitavax RS & Counter (VVC)	0.000750	0.000032	
3	Exceed	150	Helix	0.000687	0.000032	
4	Invigor	150	Vitavax RS (VV)	0.000683	0.000032	
5	Invigor	75	Helix	0.000646	0.000032	
6	Invigor	150	None	0.000611	0.000032	
7	Exceed	150	Vitavax RS (VV)	0.000571	0.000032	
8	Exceed	150	Vitavax RS & Counter (VVC)	0.000533	0.000032	
9	Invigor	75	Vitavax RS (VV)	0.000487	0.000032	
10	Invigor	75	None	0.000473	0.000032	
11	Invigor	75	Vitavax RS & Counter (VVC)	0.000416	0.000032	
12	Exceed	75	Helix	0.000414	0.000032	
13	Exceed	150	None	0.000408	0.000032	
14	Exceed	75	Vitavax RS & Counter (VVC)	0.000379	0.000032	
15	Exceed	75	Vitavax RS (VV)	0.000359	0.000032	
16	Exceed	75	None	0.000315	0.000032	

[a] Data was $\log_{10}$ converted prior to analysis.

Table 18: The effect of cultivar, target planting density, and seed treatment on the rate at which canola covered the ground at the 2000 clay loam site[a].

Rank	Parameter			Rate of Ground Cover (m^2 GDD^{-1})	Std. Error	R-squared
	Cultivar	Target Density (plant m^{-2})	Seed Treatment			
1	Invigor	150	Helix	0.000782	0.000037	0.94
2	Invigor	150	Vitavax RS (VV)	0.000708	0.000037	
3	Exceed	150	Helix	0.000703	0.000037	
4	Invigor	150	None	0.000689	0.000037	
5	Invigor	75	Helix	0.000684	0.000037	
6	Invigor	150	Vitavax RS & Counter (VVC)	0.000636	0.000037	
7	Invigor	75	Vitavax RS (VV)	0.000621	0.000037	
8	Exceed	150	Vitavax RS (VV)	0.000609	0.000037	
9	Exceed	150	Vitavax RS & Counter (VVC)	0.000605	0.000037	
10	Invigor	75	None	0.000575	0.000037	
11	Exceed	150	None	0.000573	0.000037	
12	Invigor	75	Vitavax RS & Counter (VVC)	0.000537	0.000037	
13	Exceed	75	None	0.000477	0.000037	
14	Exceed	75	Helix	0.000463	0.000037	
15	Exceed	75	Vitavax RS (VV)	0.000397	0.000037	
16	Exceed	75	Vitavax RS & Counter (VVC)	0.000356	0.000037	

[a] Data was $\log_{10}$ converted prior to analysis.

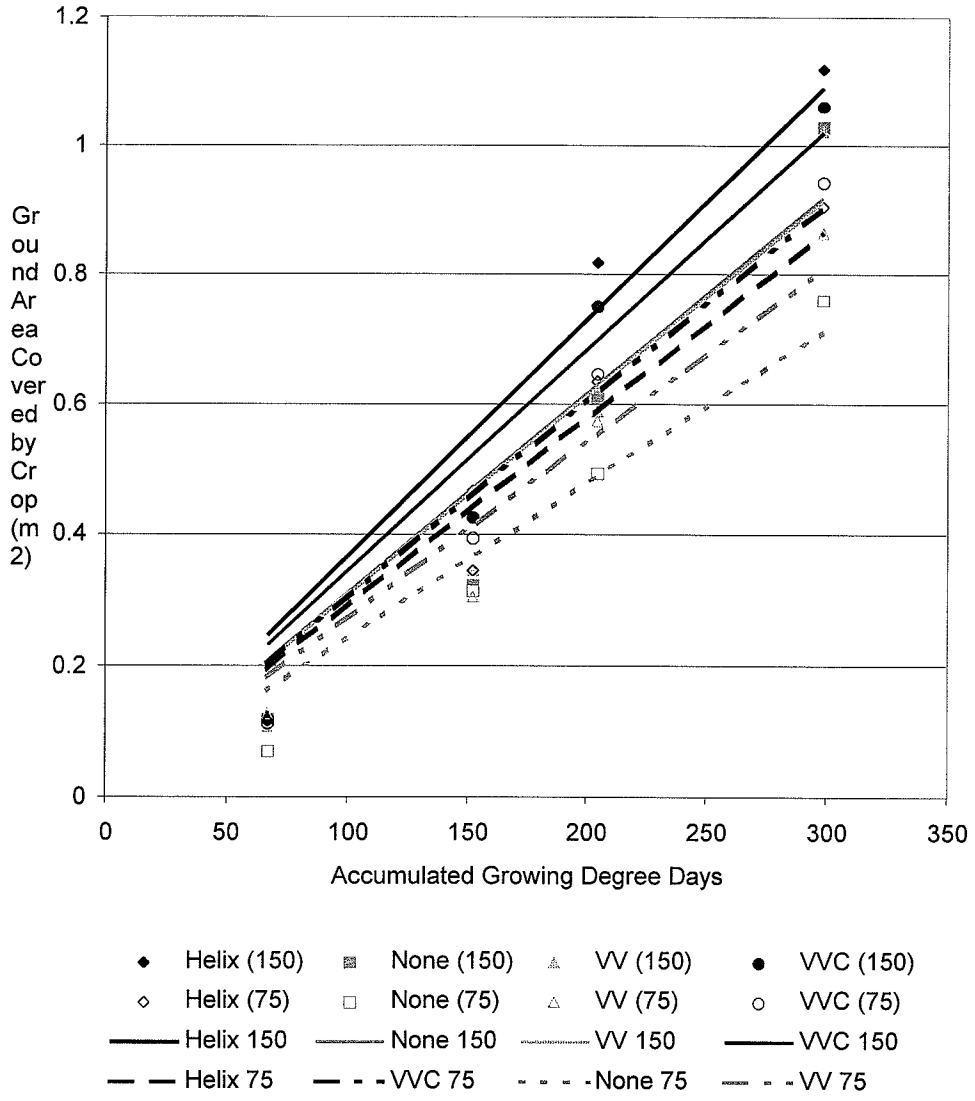


Figure 7: Invigor canola ground cover at the 1999 sandy loam site. See Table 15 for slope comparisons.
Helix = thiamethoxam, difenoconazole, fludioxonil, & metalaxyl-M
None = bare seed
Vitavax RS (VV) = lindane, carbathiin, & thiram.
Vitavax RS & Counter (VVC) = lindane, carbathiin, & thiram, plus terbufos
150 = target canola density of 150 plants m-2
75 = target canola density of 75 plants m-2

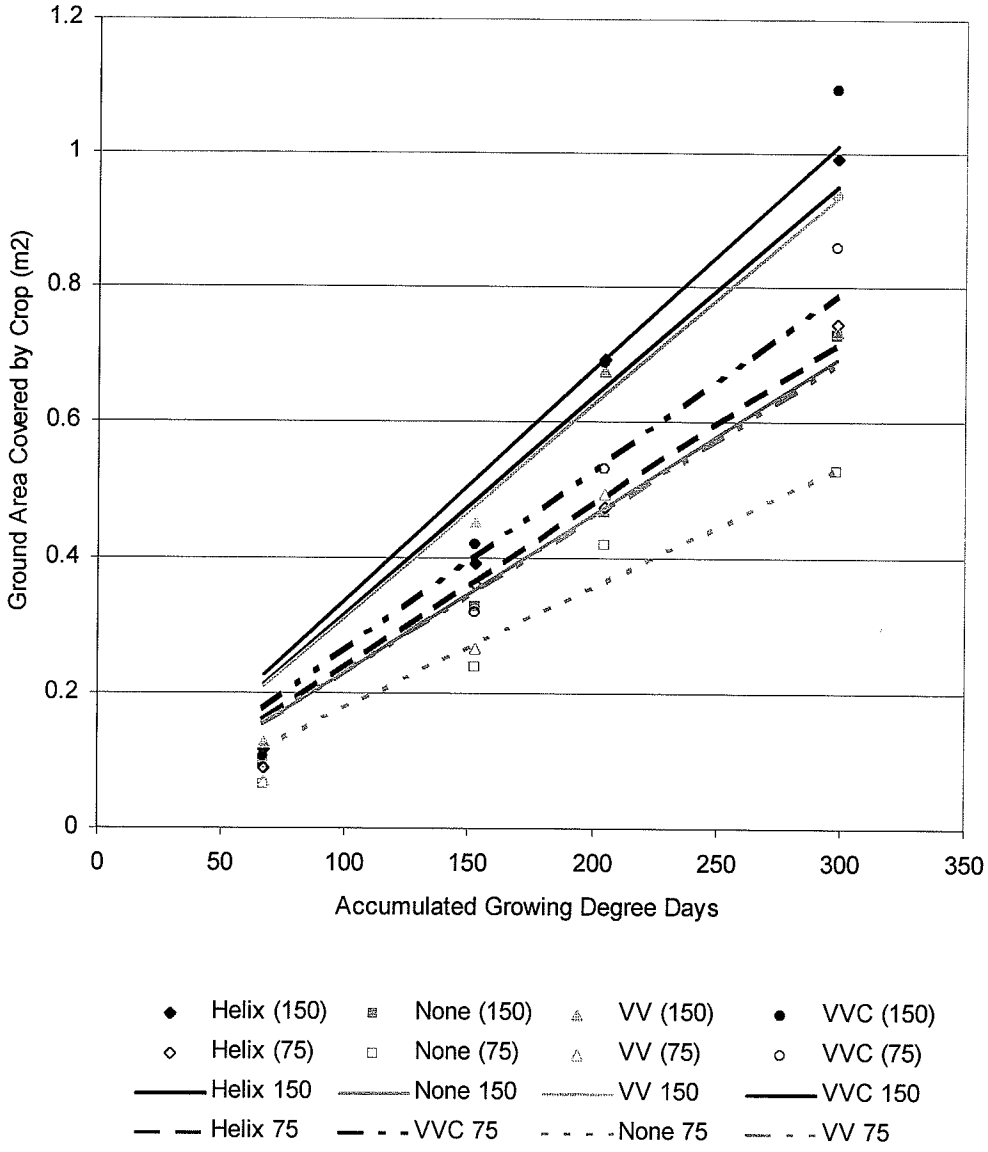


Figure 8: Exceed canola ground cover at the 1999 sandy loam site. See Table 15 for slope comparisons.
Helix = thiamethoxam, difenoconazole, fludioxonil, & metalaxyl-M
None = bare seed
Vitavax RS (VV) = lindane, carbathiin, & thiram.
Vitavax RS & Counter (VVC) = lindane, carbathiin, & thiram, plus terbufos
150 = target canola density of 150 plants m-2
75 = target canola density of 75 plants m-2

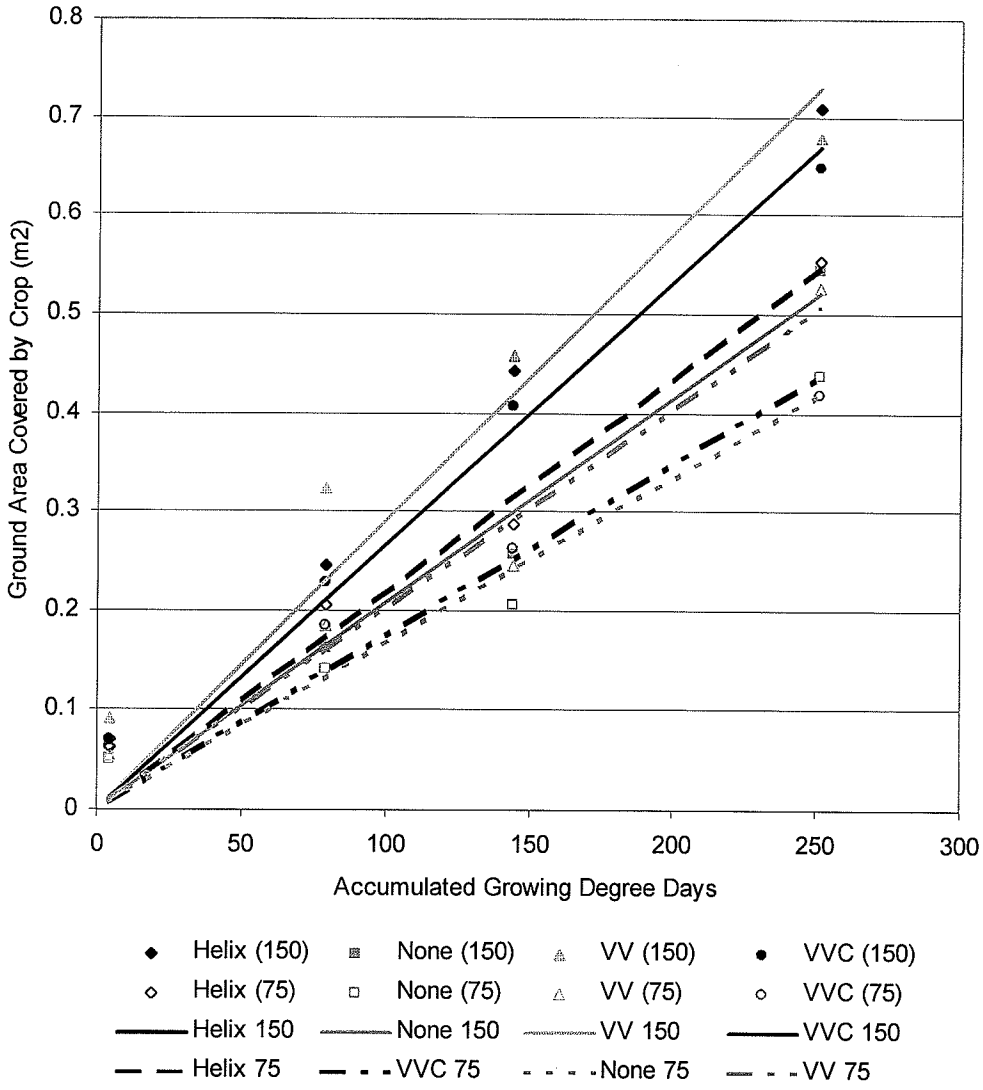


Figure 9: Invigor canola ground cover at the 2000 sandy loam site. See Table 16 for slope comparisons.
Helix = thiamethoxam, difenoconazole, fludioxonil, & metalaxyl-M
None = bare seed
Vitavax RS (VV) = lindane, carbathiin, & thiram.
Vitavax RS & Counter (VVC) = lindane, carbathiin, & thiram, plus terbufos
150 = target canola density of 150 plants m-2
75 = target canola density of 75 plants m-2

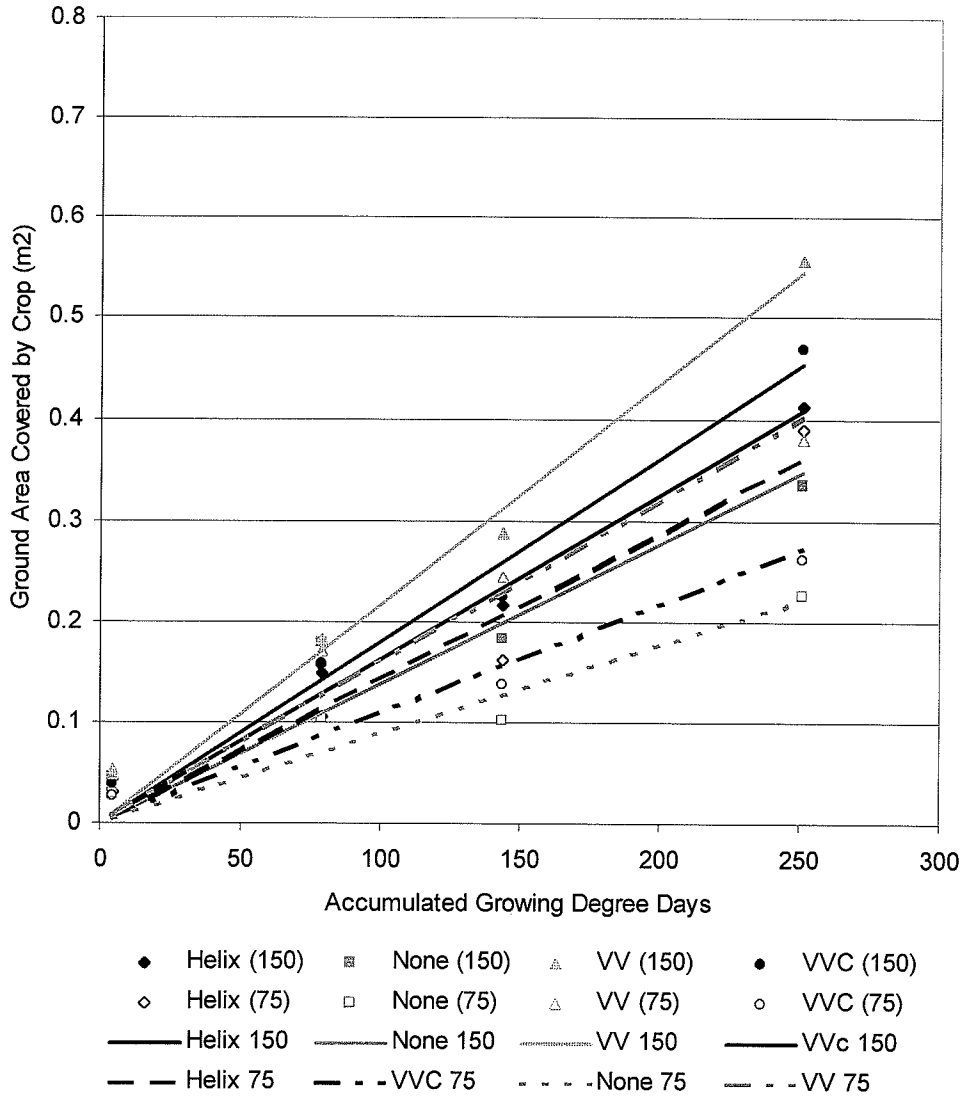


Figure 10: Exceed canola ground cover at the 2000 sandy loam site. See Table 16 for slope comparisons.
Helix = thiamethoxam, difenoconazole, fludioxonil, & metalaxyl-M
None = bare seed
Vitavax RS (VV) = lindane, carbathiin, & thiram.
Vitavax RS & Counter (VVC) = lindane, carbathiin, & thiram, plus terbufos
150 = target canola density of 150 plants m-2
75 = target canola density of 75 plants m-2

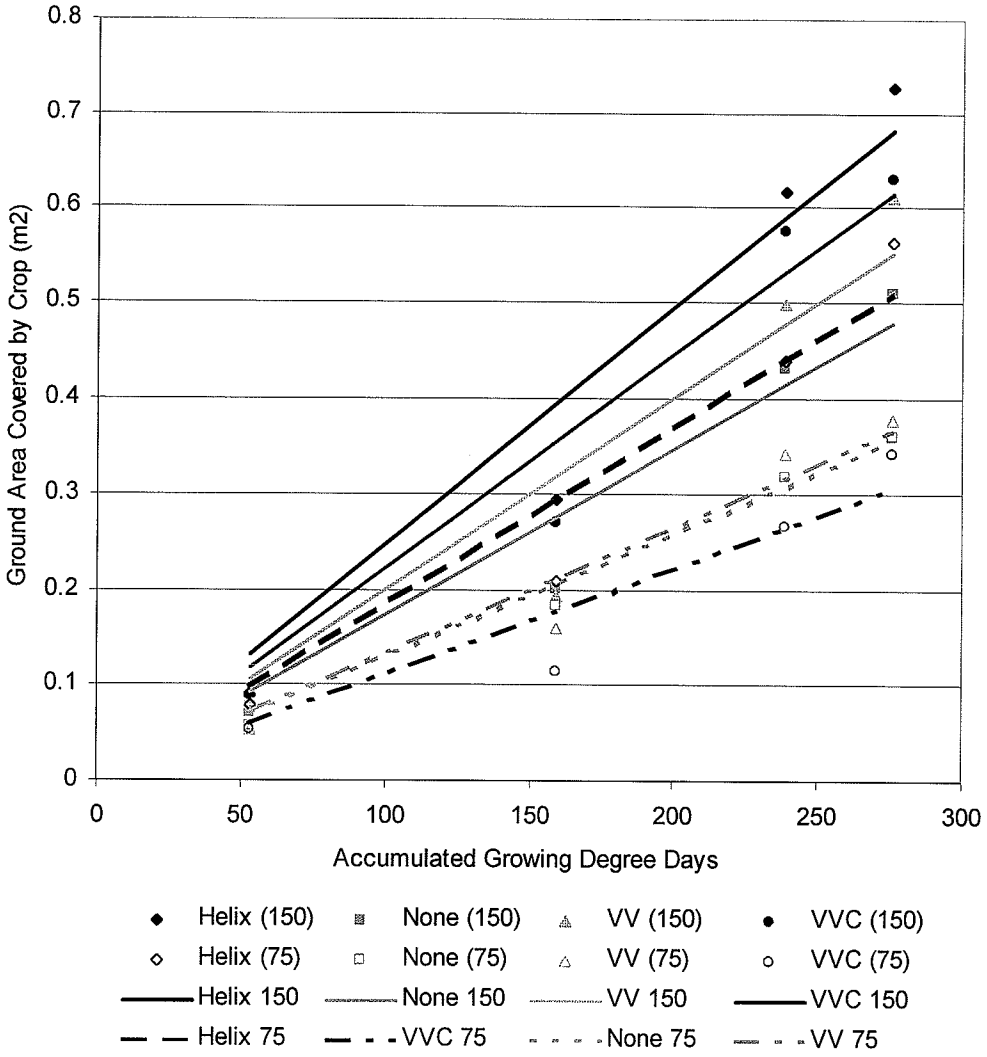


Figure 11: Invigor canola ground cover at the 2000 clay site. See Table 17 for slope comparisons.
Helix = thiamethoxam, difenoconazole, fludioxonil, & metalaxyl-M
None = bare seed
Vitavax RS (VV) = lindane, carbathiin, & thiram.
Vitavax RS & Counter (VVC) = lindane, carbathiin, & thiram, plus terbufos
150 = target canola density of 150 plants m-2
75 = target canola density of 75 plants m-2

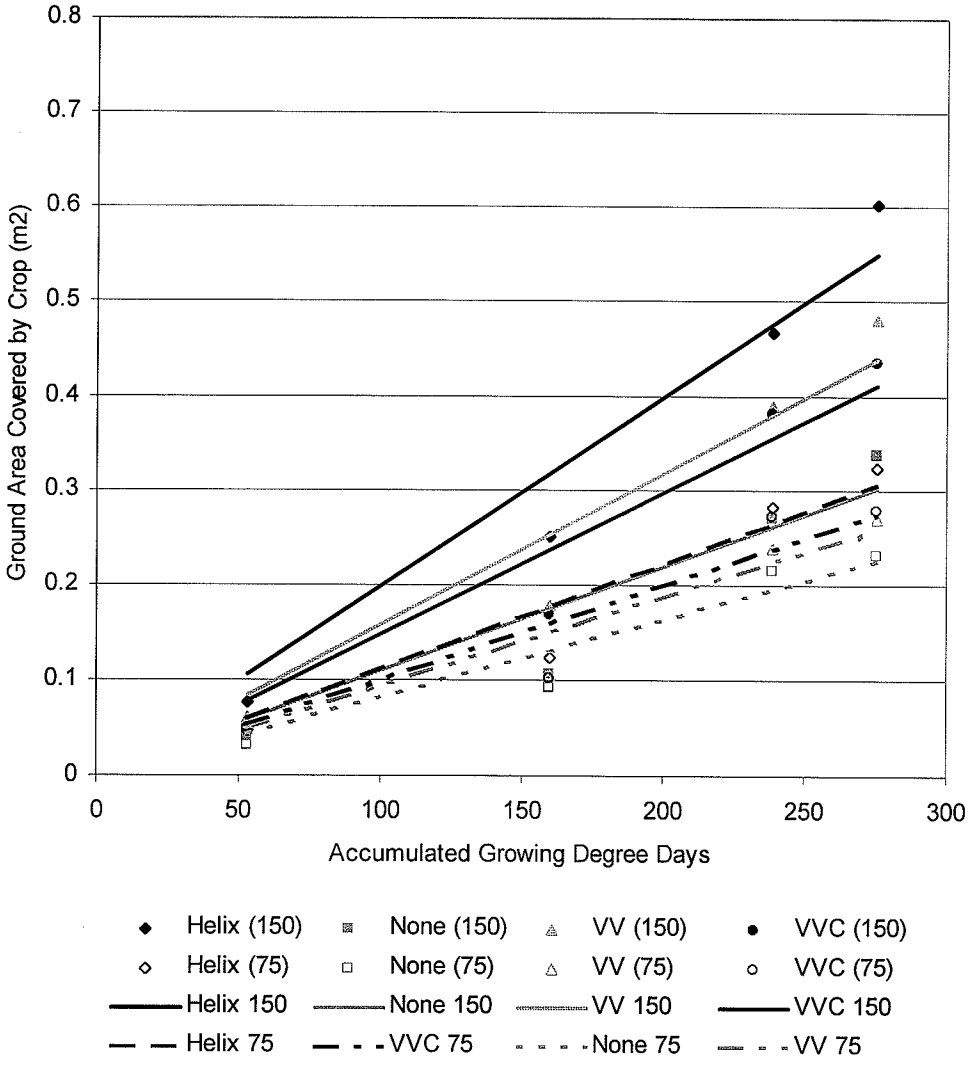


Figure 12: Exceed canola ground cover at the 2000 clay site. See Table 17 for slope comparisons.
Helix = thiamethoxam, difenoconazole, fludioxonil, & metalaxyl-M
None = bare seed
Vitavax RS (VV) = lindane, carbathiin, & thiram.
Vitavax RS & Counter (VVC) = lindane, carbathiin, & thiram, plus terbufos
150 = target canola density of 150 plants m-2
75 = target canola density of 75 plants m-2

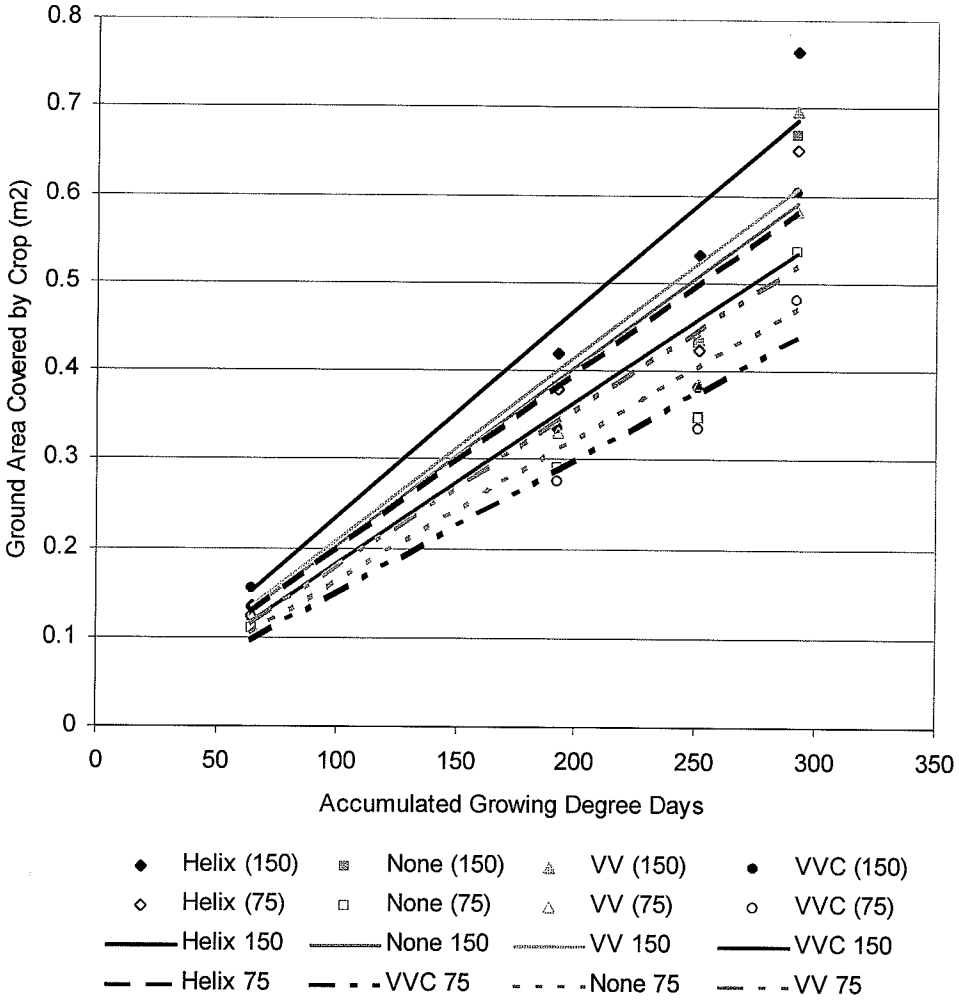


Figure 13: Invigor canola ground cover at the 2000 clay loam site. See Table 18 for slope comparisons.
Helix = thiamethoxam, difenoconazole, fludioxonil, & metalaxyl-M
None = bare seed
Vitavax RS (VV) = lindane, carbathiin, & thiram.
Vitavax RS & Counter (VVC) = lindane, carbathiin, & thiram, plus terbufos
150 = target canola density of 150 plants m-2
75 = target canola density of 75 plants m-2

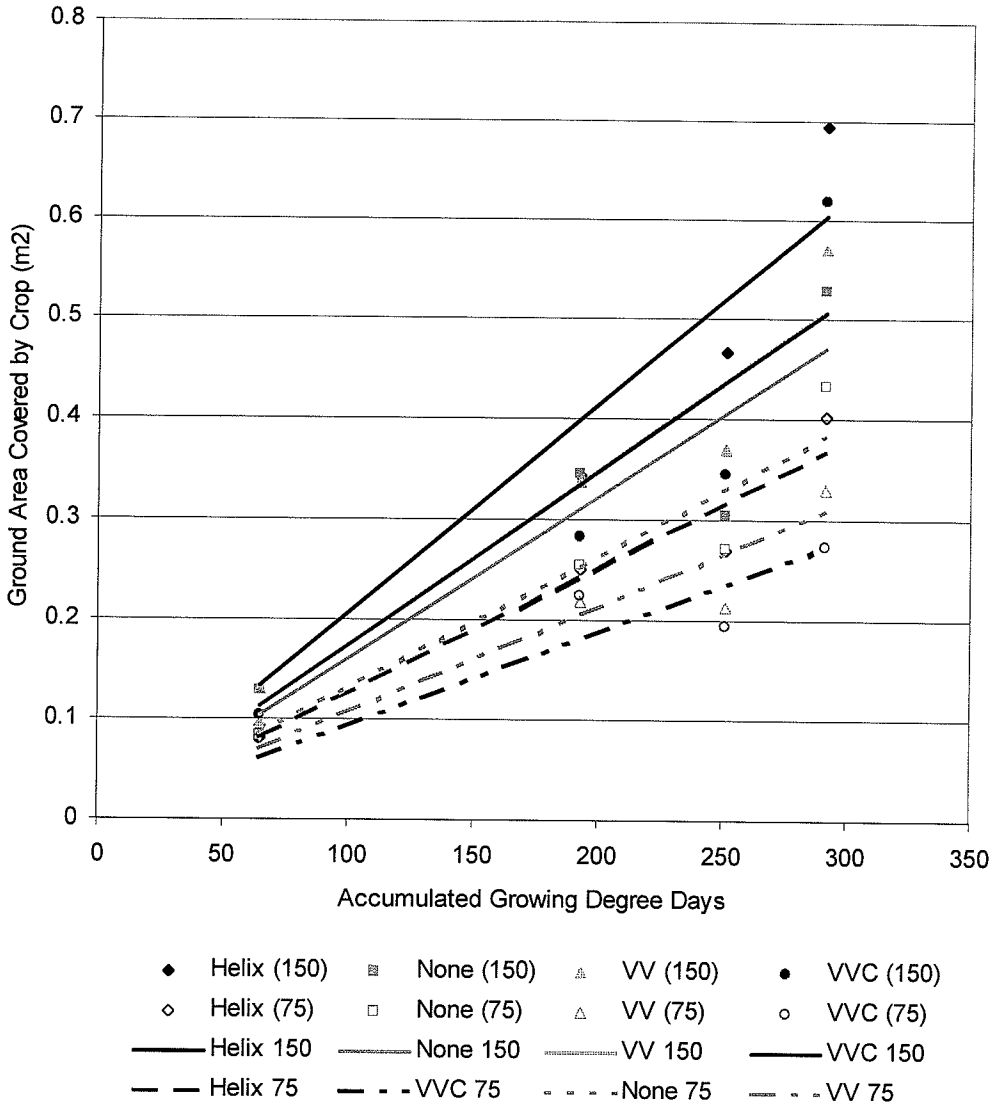


Figure 14: Exceed canola ground cover at the 2000 clay loam site. See Table 18 for slope comparisons.
Helix = thiamethoxam, difenoconazole, fludioxonil, & metalaxyl-M
None = bare seed
Vitavax RS (VV) = lindane, carbathiin, & thiram.
Vitavax RS & Counter (VVC) = lindane, carbathiin, & thiram, plus terbufos
150 = target canola density of 150 plants m-2
75 = target canola density of 75 plants m-2

Table 19: 1999 sandy loam canola ground cover per plant slope comparison*

Parameter	Slope	Std. Error	R-squared
150 plants m^{-2}	1.09E-03	2.61E-05	0.91
300 plants m^{-2}	8.13E-04	2.61E-05	

* Data was $\log_{10}$ converted prior to analysis

Table 20: 2000 sandy loam canola ground cover per plant slope comparison*

Parameter	Slope	Std. Error	R-squared
150 plants m^{-2}	1.66E-05	6.67E-07	0.82
300 plants m^{-2}	1.10E-05	6.67E-07	

* Data was $\log_{10}$ converted prior to analysis

Table 21: 2000 clay canola ground cover per plant slope comparison*

Parameter	Slope	Std. Error	R-squared
Helix	1.19E-05	6.07E-07	0.81
None	8.85E-06	6.07E-07	
Vitavax RS (VV)	8.70E-06	6.07E-07	
Vitavax RS & Counter (VVC)	8.78E-06	6.07E-07	

* Data was $\log_{10}$ converted prior to analysis

Table 22: 2000 clay loam canola ground cover per plant slope comparison*

Parameter	Slope	Std. Error	R-squared
Invigor (75 plants m^{-2})	1.46E-05	4.57E-07	0.89
Invigor (150 plants m^{-2})	1.14E-05	4.57E-07	
Exceed (75 plants m^{-2})	9.46E-06	4.57E-07	
Exceed (150 plants m^{-2})	8.52E-06	4.57E-07	

* Data was $\log_{10}$ converted prior to analysis

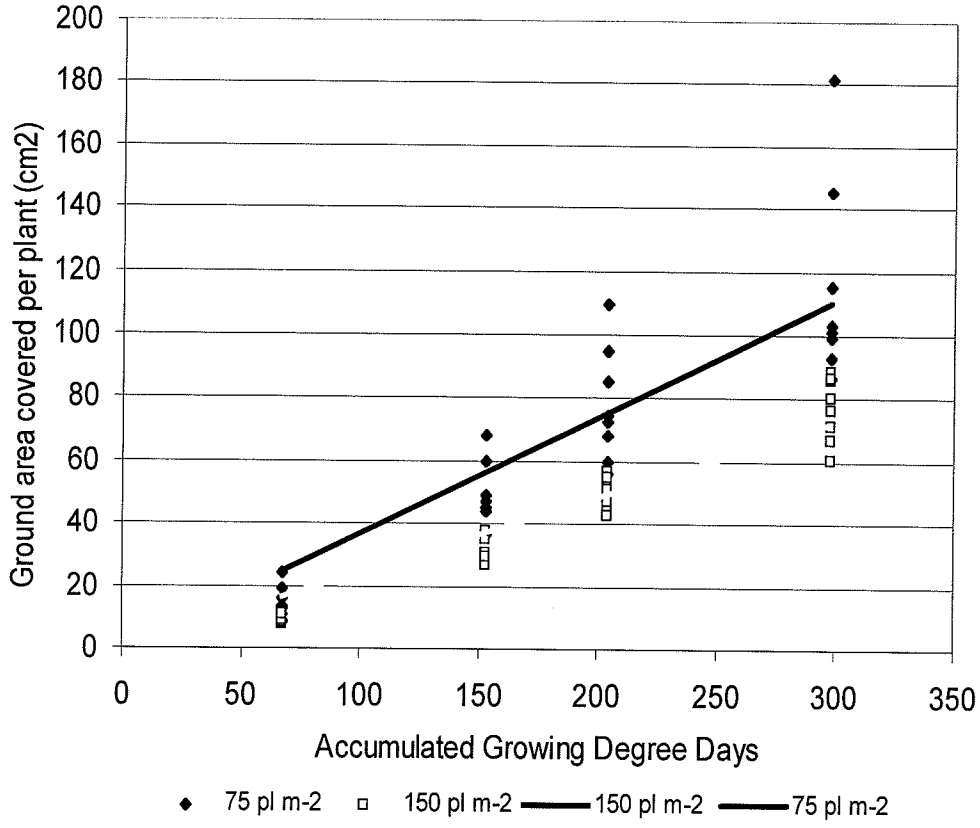


Figure 15: Canola ground cover per plant at the 1999 sandy loam site. See Table 19 for slope comparisons.
75 = target canola density of 75 plants m-2
150 = target canola density of 150 plants m-2

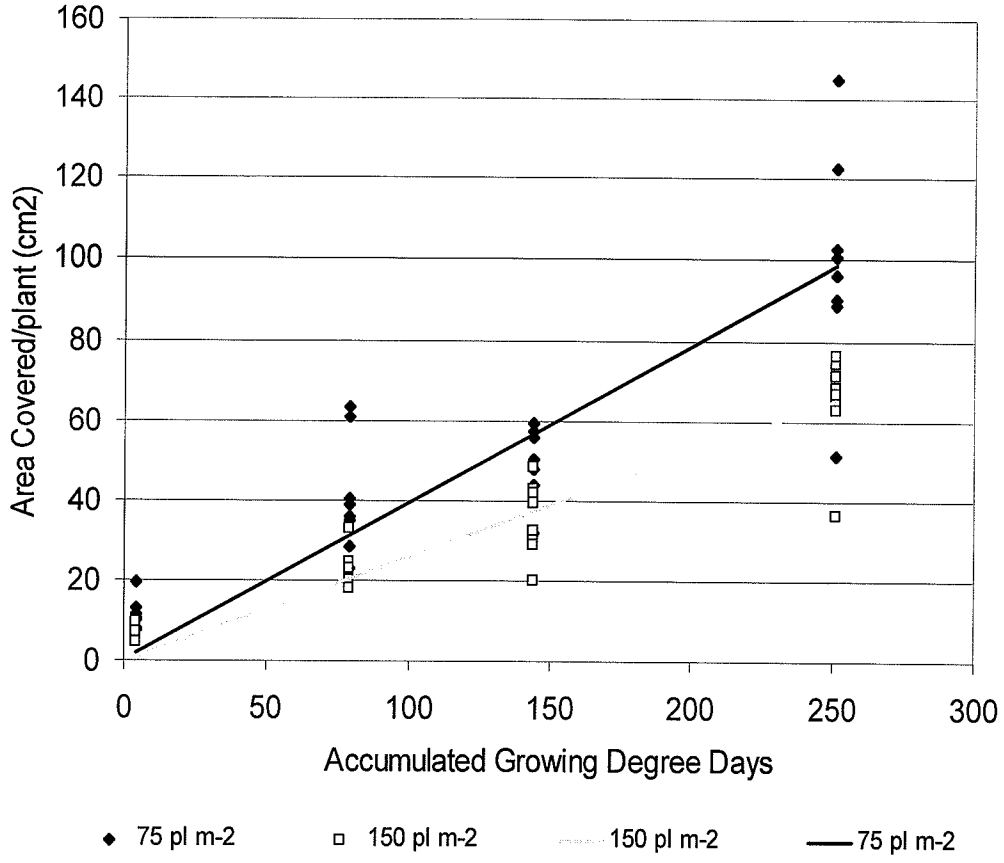


Figure 16: Canola ground cover per plant at the 2000 sandy loam site. See Table 20 for slope comparisons.
75 = target canola density of 75 plants m-2
150 = target canola density of 75 plants m-2

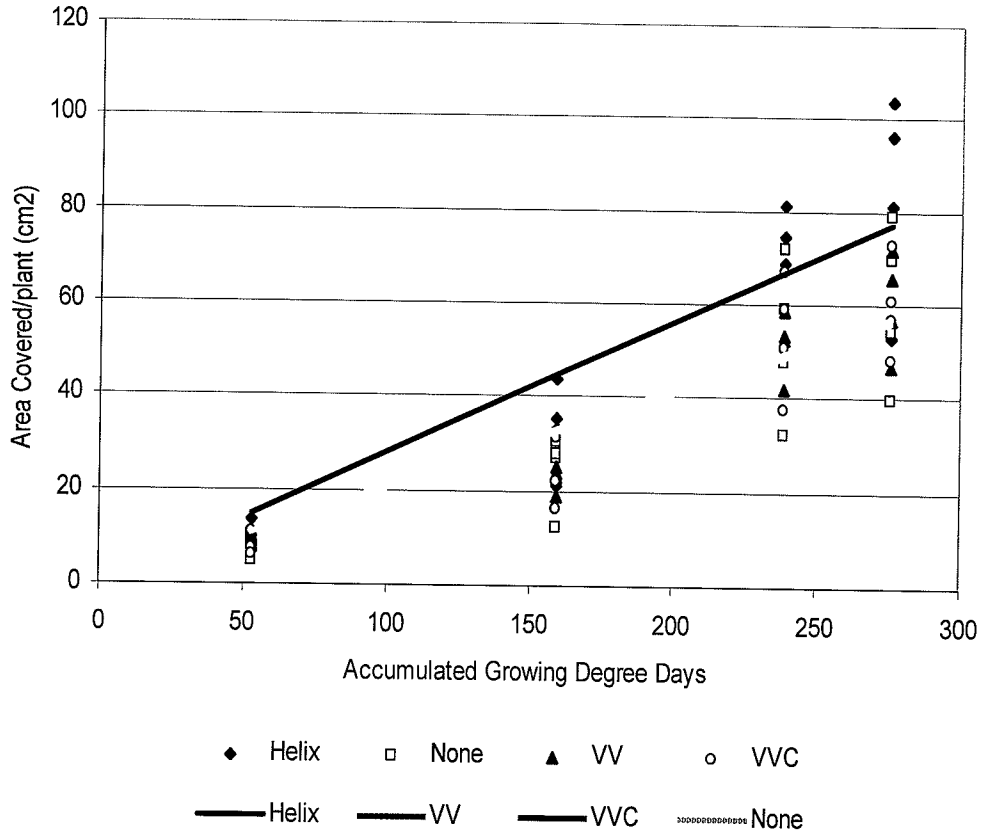


Figure 17: Canola ground coverage per plant at the 2000 clay site. See Table 21 for slope comparisons.
Helix = thiamethoxam, difenoconazole, fluidioxinil, & metalaxyl-M
None = Bare seed
Vitavax RS (VV) = lindane, carbathiin, & thiram
Vitavax RS & Counter (VVC) = lindane, carbathiin, & thiram plus terbufos

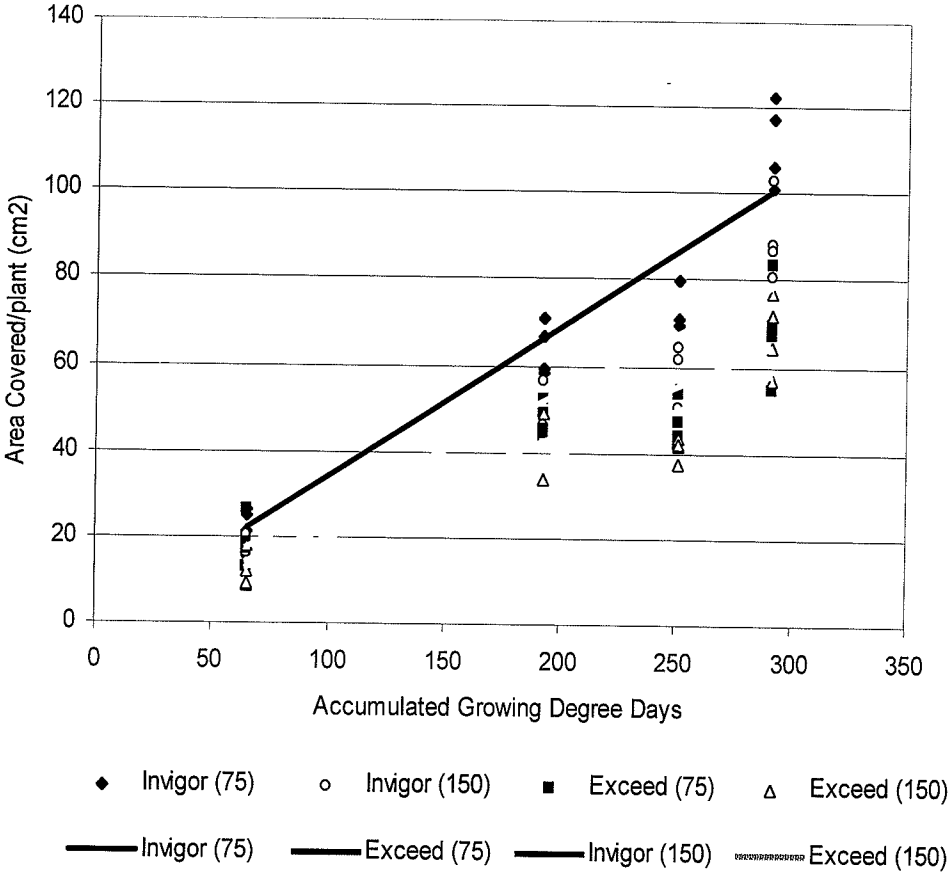


Figure18: Canola ground coverage per plant at the 2000 clay loam site. See Table 22 for slope comparisons.
75 = target canola density of 75 plants -2
150 = target canola density of 150 plants -2

Canola biomass production reflects the effects of flea beetle feeding, seeding rate, and cultivar on crop growth. Canola biomass was examined in two ways; overall production, and the rate at which it was accumulated. Overall biomass production measures the photosynthetic success of a plant, and a consequence of increasing the rate of crop biomass accumulation is a possible reduction in weed biomass and decreased dockage.

Overall canola biomass production was less affected by seed treatment relative to seeding rate and cultivar at the 2000 clay and clay loam sites, but seed treatment had more influence at the sandy loam sites in 1999 and 2000 (Table 15). The mixture of thiamethoxam, difenoconazole, fluidioxonil, and metalaxyl-M (Helix) and the mixture of lindane, carbathiin, and thiram with terbufos (Vitavax RS & Counter) were the only seed treatments that affected overall biomass, with both having greater canola biomass relative to the mixture of lindane, carbathiin, & thiram (Vitavax RS) and the non-treated control (Table 28). The rate of biomass accumulation was unaffected by seed treatment, suggesting that any growth inhibition effect from flea beetle feeding disappeared prior to sampling.

Increasing seeding rate resulted in smaller canola plants (Figures 19-21) and Invigor plants were larger than Exceed plants. Also, Invigor generally accumulating biomass at a faster rate than Exceed with Invigor at target density 150 plants m^{-2} growing fastest in all cases (Figures 19&20). Furthermore, the difference between seeding rates was greater for Invigor, suggesting it was more capable of capturing available space and possibly more competitive than Exceed. Overall, canola biomass production was

affected by flea beetle feeding, cultivar and seeding rate, with the relative importance shifting depending on the location.

The effects of seeding rate and cultivar on canola growth were also evident in barley biomass production. Increasing canola density caused a decrease in barley biomass in all cases (Figures 23-26) and Invigor suppressed barley growth more than Exceed at the 2000 clay and clay loam sites (Figures 25&26). Despite having an influence on canola biomass production, seed treatment had no effect on barley biomass.

In general, seed treatment did not have an overwhelming effect on canola biomass production compared to cultivar and seeding rate, and had no role in suppressing barley biomass. As a result, the influence of cultivar and seeding rate on canola growth and in turn barley biomass suppression may be greater than that of seed treatment. In these experiments, any reduction in canola biomass caused by flea beetle feeding did not seem to impede canola's ability to suppress weed biomass.

Table 23: Contribution of Cultivar, the presence/absence of weeds, seeding rate, and seed treatment to total variation for canola biomass calculated from ANOVA[x]

	1999 Sandy Loam			2000 Sandy Loam			2000 Clay			2000 Clay Loam		
Source	df	% total	Signif.[z]	df	% total	Signif.	df	% total	Signif.	df	% total	Signif.
Error	472	5.5%	-	474	8.0%	-	460	8.1%	-	474	8.3%	-
Replication	3	0.3%	***	3	0.7%	***	3	0.3%	**	3	0.3%	**
Growing degree Days	3	90.3%	***	3	88.2%	***	3	88.4%	***	3	86.9%	***
Cultivar	1	1.5%	***	1	0.6%	***	1	1.5%	***	1	0.3%	***
Presence/absence of Weeds	1	0.07%	*	1	0.1%	*	1	<0.1%	NS	1	0.3%	***
Seeding Rate	3	0.3%	***	3	0.5%	***	3	0.8%	***	3	2.9%	***
Seed Treatment	3	1.5%	***	3	1.1%	***	3	0.4%	***	3	0.2%	**

[z]Signif. = Significance

*,**,***Significant at p = 0.05, p = 0.01, and p = 0.001, respectively; NS, not significant

[x]Data presented only for main treatment and not interactions

Table 24: Parameter coefficients for canola biomass accumulation* at the 1999 sandy loam site.

Parameter	Parameter Estimate	Std. Error	R-squared
Slope_Invigor at target density 150 plants m^{-2}	0.0055	0.0001	0.96
Slope_Invigor at target density 300 plants m^{-2}	0.0051	0.0001	
Slope_Exceed at target density 150 plants m^{-2}	0.0049	0.0001	
Slope_Exceed at target density 300 plants m^{-2}	0.0048	0.0001	
Intercept	-0.7172	0.0253	

* Data was $\log_{10}$ converted prior to analysis

Table 25: Parameter coefficients for canola biomass accumulation* at the 2000 sandy loam site.

Parameter	Parameter Estimate	Std. Error	R-squared
Slope_Invigor at target density 150 plants m^{-2}	0.0039	0.0001	0.95
Slope_Invigor at target density 300 plants m^{-2}	0.0035	0.0001	
Slope_Exceed at target density 150 plants m^{-2}	0.0035	0.0001	
Slope_Exceed at target density 300 plants m^{-2}	0.0034	0.0001	
Intercept	-0.4852	0.0360	

* Data was $\log_{10}$ converted prior to analysis

Table 26: Parameter coefficients for canola biomass accumulation* at the 2000 clay site.

Parameter	Parameter Estimate	Std. Error	R-squared
Slope_Target density 150 plants m^{-2}	0.0039	0.0001	0.93
Slope_Target density 300 plants m^{-2}	0.0035	0.0001	
Intercept	-0.4013	0.0415	

* Data was $\log_{10}$ converted prior to analysis

Table 27:. Parameter coefficients for canola biomass accumulation* at the 2000 clay loam site.

Parameter	Parameter Estimate	Std. Error	R-squared
Slope_Invigor at target density 150 plants m^{-2}	0.0036	0.0001	0.93
Slope_Invigor at target density 300 plants m^{-2}	0.0030	0.0001	
Slope_Exceed at target density 150 plants m^{-2}	0.0034	0.0001	
Slope_Exceed at target density 300 plants m^{-2}	0.0029	0.0001	
Intercept	-0.23732	0.0371	

* Data was $\log_{10}$ converted prior to analysis

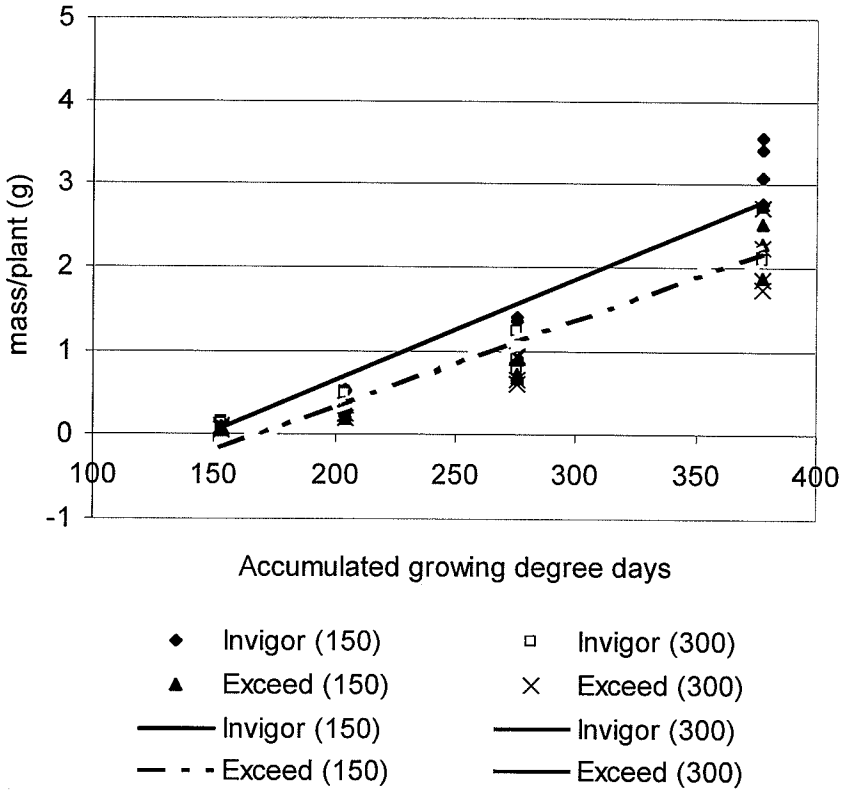


Figure 19: The effect of cultivar and target planting density on canola biomass accumulation rate at the 1999 sandy loam site. For coefficients see Table 24.
150 = target canola density of 150 plants m-2
300 = target canola density of 300 plants m-2

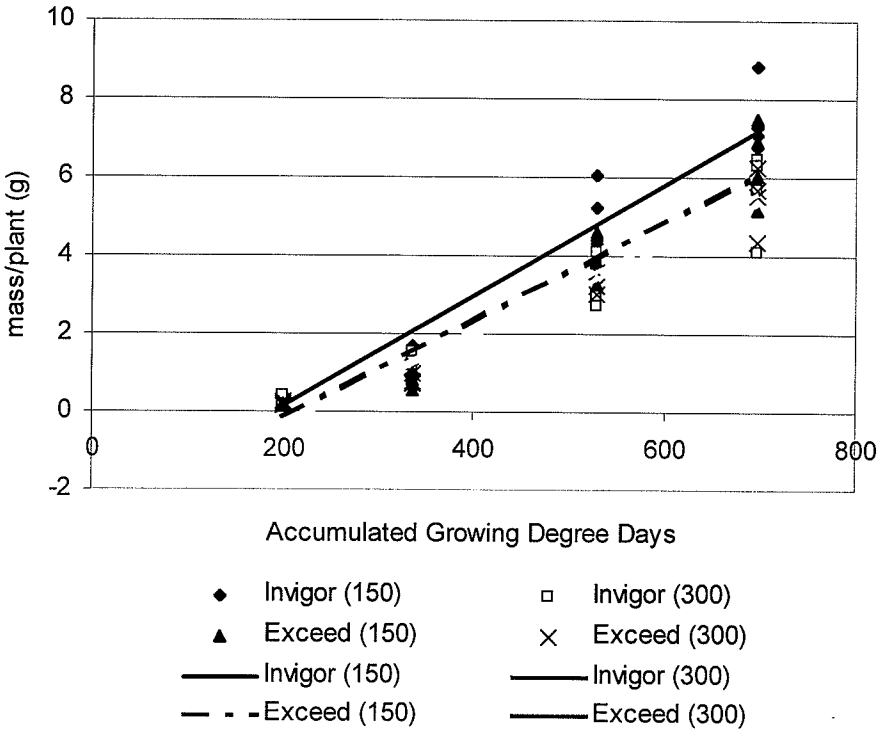


Figure 20: The effect of cultivar and target planting density on canola biomass accumulation rate at the 2000 sandy loam site. For coefficients see Table 25.
150 = target canola density of 150 plants m-2
300 = target canola density of 300 plants m-2

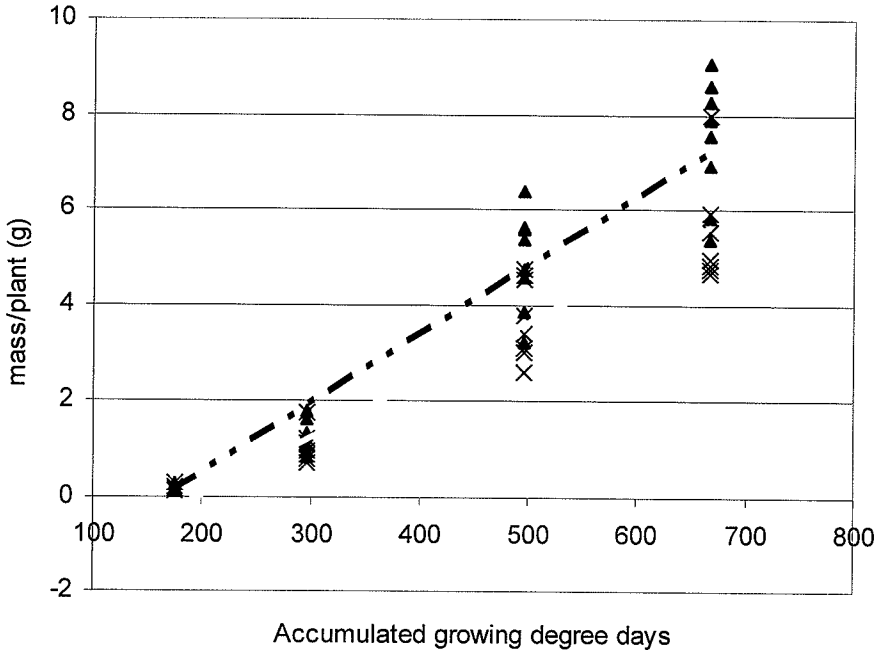


Figure 21: The effect of target planting density on canola biomass accumulation rate at the 2000 clay site. For coefficients see Table 26.
150 = target canola density of 150 plants m-2
300 = target canola density of 300 plants m-2

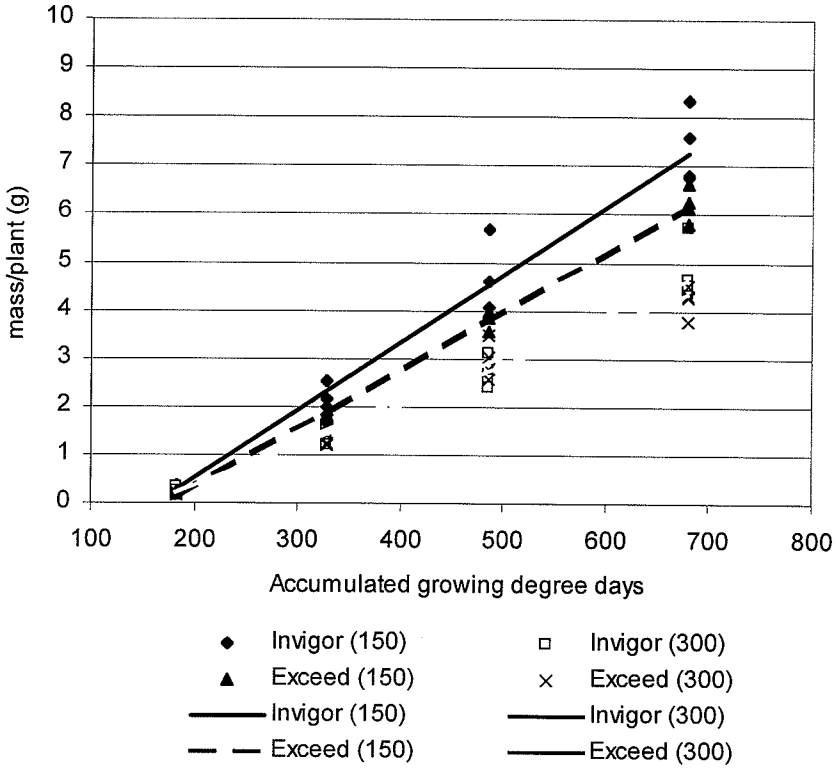


Figure 22: The effect of cultivar and target planting density on canola biomass accumulation rate at the 2000 clay loam site. For coefficients see Table 27.
150 = target canola density of 150 plants m-2
300 = target canola density of 300 plants m-2

Table 28: The effect of seed treatment on canola biomass production* averaged over four sample dates.

Year	Location	Seed Treatment	Mass (g)	Std. Error	LSD/location
1999	Sandy Loam	Helix	1.08	0.09	a
1999	Sandy Loam	Vitavax RS	0.89	0.08	b
1999	Sandy Loam	Vitavax RS & Counter	1.11	0.10	a
1999	Sandy Loam	Bare Seed	0.79	0.08	c
2000	Sandy Loam	Helix	3.08	0.25	a
2000	Sandy Loam	Vitavax RS	2.56	0.22	b
2000	Sandy Loam	Vitavax RS & Counter	3.29	0.27	a
2000	Sandy Loam	Bare Seed	2.51	0.22	b
2000	Clay	Helix	3.09	0.26	a
2000	Clay	Vitavax RS	2.76	0.25	b
2000	Clay	Vitavax RS & Counter	3.19	0.28	a
2000	Clay	Bare Seed	2.65	0.24	b
2000	Clay Loam	Helix	2.85	0.21	ab
2000	Clay Loam	Vitavax RS	2.58	0.19	c
2000	Clay Loam	Vitavax RS & Counter	2.98	0.23	a
2000	Clay Loam	Bare Seed	2.69	0.21	bc

*Significance tests performed on $\log_{10}$ transformed data
1999 clay site was not analyzed due to herbicide damage

Table 29: The effect of cultivar on canola biomass production averaged over four sampling dates.

Year	Location	Cultivar	mean	Std. Error	LSD/location
1999	Sandy Loam	Invigor	1.10	0.07	a
1999	Sandy Loam	Exceed	0.85	0.06	b
2000	Sandy Loam	Invigor	3.07	0.18	a
2000	Sandy Loam	Exceed	2.65	0.16	b
2000	Clay	Invigor	3.30	0.19	a
2000	Clay	Exceed	2.55	0.16	b
2000	Clay Loam	Invigor	2.95	0.16	a
2000	Clay Loam	Exceed	2.60	0.14	b

*Significance tests performed on $\log_{10}$ transformed data

Table 30: The effect of seeding rate on canola biomass production averaged over four sample dates.

Year	Location	Target Plant Density	mean	Std. Error	LSD/location
1999	Sandy Loam	150	1.05	0.07	a
1999	Sandy Loam	300	0.89	0.05	b
2000	Sandy Loam	150	3.18	0.19	a
2000	Sandy Loam	300	2.54	0.15	b
2000	Clay	150	3.34	0.21	a
2000	Clay	300	2.50	0.15	b
2000	Clay Loam	150	3.30	0.17	a
2000	Clay Loam	300	2.24	0.11	b

*Significance tests performed on $\log_{10}$ transformed data

Table 31: Parameter estimates for barley biomass suppression at the 1999 sandy loam site.*

Parameter	Parameter Estimate	Std. Error	R-squared
Intercept	2.90211	0.08140	0.35
Slope	0.00277	0.00042	

* Data was $\log_{10}$ converted prior to analysis

Table 32: Parameter estimates for barley biomass suppression at the 2000 sandy loam site.*

Parameter	Parameter Estimate	Std. Error	R-squared
Intercept	3.00615	0.05261	0.22
Slope	0.00123	0.00024	

* Data was $\log_{10}$ converted prior to analysis

Table 33: Parameter estimates for barley biomass suppression at the 2000 clay site.*

Parameter	Parameter Estimate	Std. Error	R-squared
Intercept (I)	2.89376	0.04870	0.48
Slope_Invigor	0.00209	0.00027	
Slope_Exceed	0.00059	0.00022	

* Data was $\log_{10}$ converted prior to analysis

Table 34: Parameter estimates for barley biomass suppression at the 2000 clay loam site.*

Parameter	Parameter Estimate	Std. Error	R-squared
Intercept_Invigor	2.72977	0.03973	0.42
Intercept_Exceed	2.90484	0.03949	
Slope	0.00105	0.00015	

* Data was $\log_{10}$ converted prior to analysis

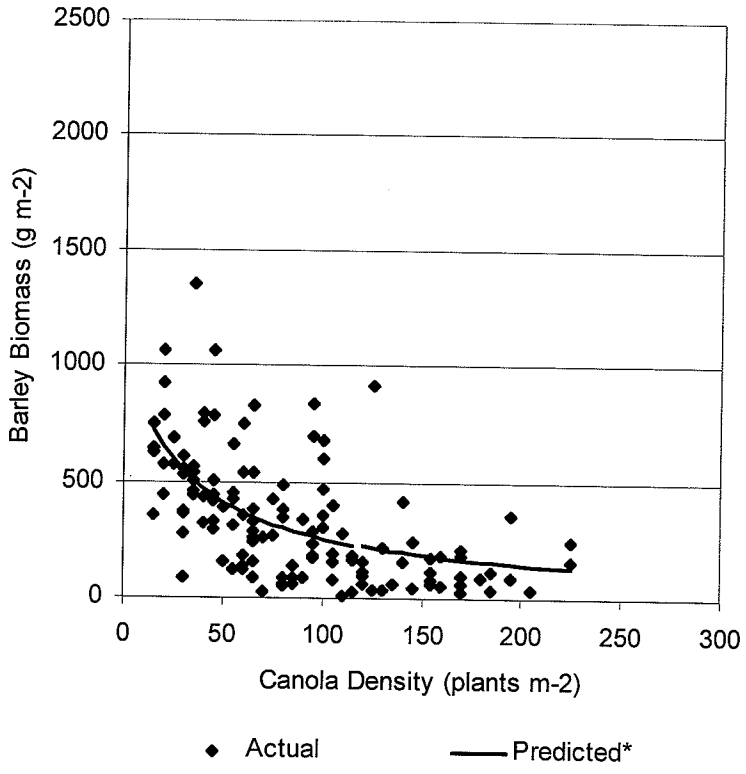


Figure 23: Barley biomass suppression at the 1999 sandy loam site. For coefficients see Table 31. *Model used for predicted values based on modified equation from O'Donovan (1988)

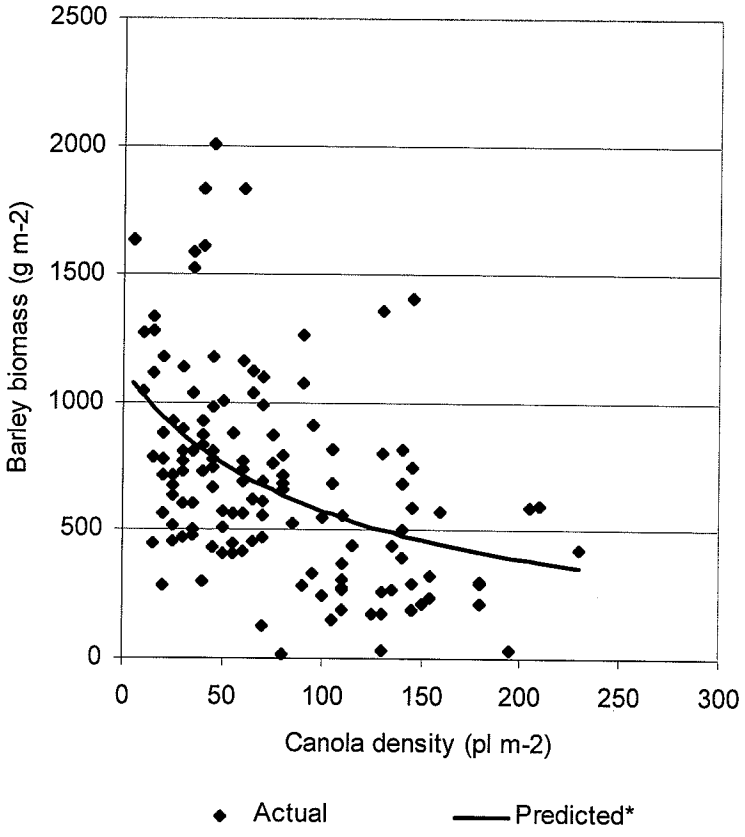


Figure 24: Barley biomass suppression at the 2000 sandy loam site. For coefficients see Table 32.
*Model used for predicted values based on modified equation from O'Donovan (1988)

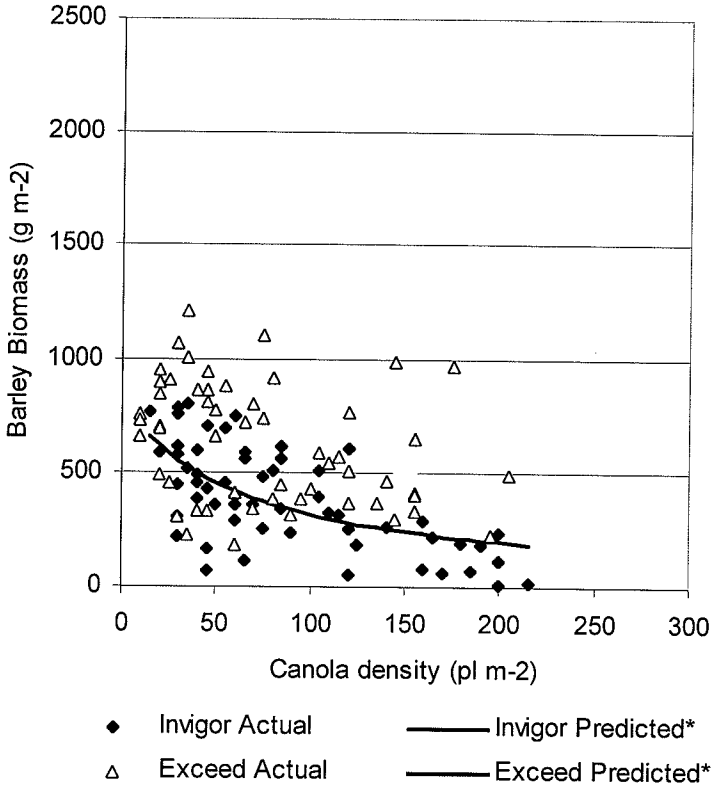


Figure 25: Barley biomass suppression at the 2000 clay site. For coefficient comparisons see Table 33.
*Model used for predicted values based on modified equation from O'Donovan (1988)

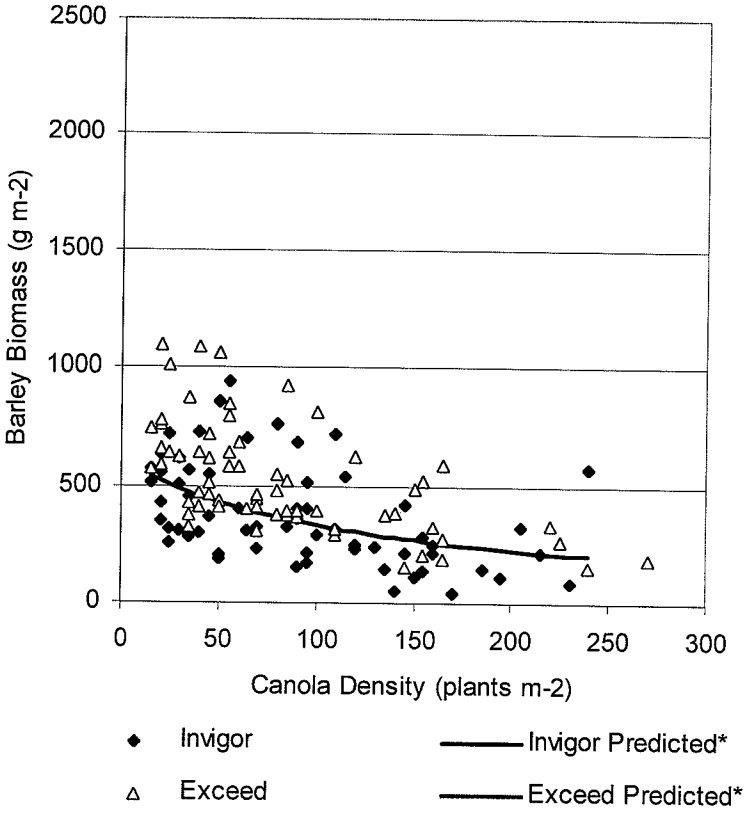


Figure 26: Barley biomass suppression at the 2000 clay loam site. For coefficient comparisons see Table 34. *Model used for predicted values based on modified equation from O'Donovan (1988)

Increasing the seeding rate allowed the crop to cover the ground more quickly but decreased individual plant biomass. This demonstrates what many authors have documented in the past (Morrison et al, 1990; McGreggor, 1986; Degenhardt & Kondra, 1981) and verifies Harper's (1977) discussion on space capture, intraspecific competition, and the law of constant yield. Invigor canola covered the ground more quickly than Exceed canola at only one site but consistently had greater biomass than Exceed, demonstrating hybrid vigor found in other hybrid crops (Lindquist & Mortensen, 1998), and suggesting increased growth was directed more to height increase than lateral spread.

Despite sustaining considerable damage, non-treated seedlings covered the ground as quickly as treated seedlings at all but one site, even though biomass was affected by seed treatment at all sites, suggesting height and not ground cover was affected. Romanow et al (1977) reported >shot gun blast' damage similar to what was found in this study, as well as stunted growth for canola seedlings with excessive flea beetle damage, especially during hot dry growing conditions. Lamb (1984) also noted severe stunting, with lindane treated seedlings weighing nearly twice as much as non-treated seedlings. Data for ground cover and biomass suggest stunting was not as prevalent in this study; however, weather conditions were near optimal for canola growth and Burgess (1977) suggested that under cool, damp weather conditions plants might better withstand the damage flea beetles inflicted upon them. It could be the effect of flea beetle feeding on seedling growth is magnified by poor growing conditions. Flea beetles prefer hot dry conditions. South Western Manitoba typically experiences cooler temperatures than the Red River Valley (Appendix), therefore data collected by Lamb (1984) may be more representative of the Red River Valley. As a result treating canola

result, treating canola seed with insecticide may not always be necessary in south western Manitoba, especially when growing conditions are good and zero tillage is practiced.

Greenhouse Experiment

Results suggesting seed treatment had little impact on canola growth in the field prompted a greenhouse study of their effect on canola competition in the absence of pests. The suggestion of growth stimulation from seed treatment (Foster & Brust, 1995) has been made for canola, but studies with wheat has shown the opposite to be true (Montfort et al, 1995).

In the present study, the non-treated canola and canola treated with a mixture of thiamethoxam, difenoconazole, fludiozonil, and metalaxyl-M (Helix) had similar competition ratios and both treatments displayed competitive ratios that were higher than canola treated with a mixture of lindane, carbathiin, and thiram (Vitavax RS) (Table 35). Therefore, in the absence of pests, treating canola seed with a mixture of lindane, carbathiin and thiram (Vitavax RS) had an overall negative effect on canola growth and barley suppression. In the field, seed treated with the mixture of lindane, carbathiin, and thiram (Vitavax RS) did not reduce growth because inhibition effects were counteracted by protection from pests (Table 28). Furthermore, adding terbufos to the mixture of lindane, carbathiin, and thiram (Vitavax RS & Counter) increased protection from pests and further masked any negative effects on growth. This issue obviously needs more investigation, but these results do raises questions about the risk of the prophylactic use of seed treatment in canola.

Table 35: Competitive ratio[a] for canola against volunteer barley in greenhouse studies.

Treatment	Mean	Stderr	LSD (p>0.05)
Nontreated Canola:Barley	0.52	0.03	a
Canola treated with Helix[b]:Barley	0.47	0.03	a
Canola treated with Vitavax RS[c]:Barley	0.38	0.03	b

[a]Competitive ratio = canola mass (g) / volunteer barley mass (g)
[b]Helix = thiamethoxam, difenoconazole, fluidioxonil, & metalaxyl-M
[c]Vitavax RS = lindane, carbathiin, & thiram

Canola Stem Disease

Stem diseases such as sclerotinia and blackleg can reduce canola yield if given the proper environment and circumstances (Martens et al, 1994). Apparent improvements in agronomy at one level without considering possible implications later may further complicate the system. For example, increasing plant density or with holding protection from insects may promote disease outbreaks because of higher canopy humidity or plants weakened by insect feeding damage. Documenting if agronomic modifications affect disease infestation later in the season is therefore important.

Diseases present within study were sclerotinia, blackleg and aster yellows. Overall infestations for sclerotina and aster yellows were low with 1-14% of the plants having basal sclerotinia lesions, and only 1-2% infected with Aster yellows (Table 36). Basal blackleg lesions were also rare except for the 1999 sandy loam site which had 33% of the plants infected. The sandy loam and clay sites sustained a small amount of hail damage in 2000 resulting in sclerotinia in the upper portion of the canopy, with 84% and 30% of the plants infected, respectively. Though basal sclerotina is responsible for the majority of canola yield loss, data was collected for comparative purposes.

Seeding rate had contradicting effects on disease prevalence with equal trends showing both increased and decreased disease prevalence. The Exceed variety had more

disease than the Invigor variety and there was generally more disease when weeds were controlled but differences were small, averaging around 4-6%.

In general, neither seeding rate nor seed treatment showed any consistent trend in late season stem disease prevalence and differences between weedy and non weedy treatments were small. As a result, disease infestation was considered to be uniform for each site, with canola stem disease having very minimal effect, if any on differences caused by treatments.

Table 36: Canola stem disease infestation (percent of plant's infected)

Year	Site	Disease	Mean Infestation (%)	Std Error
1999	Clay	Basal Sclerotinia	11.5	0.5
1999	Clay	Basal Blackleg	5.4	0.4
1999	Clay	Aster Yellows	0.7	0.1
1999	Sandy Loam	Basal Sclerotinia	14.1	0.7
1999	Sandy Loam	Basal Blackleg	33.5	1.3
1999	Sandy Loam	Aster Yellows	1.7	0.2
2000	Sandy Loam	Basal Sclerotinia	1.0	0.1
2000	Sandy Loam	Sclerotinia (other than basal)	84.3	1.1
2000	Sandy Loam	Basal Blackleg	0.6	0.1
2000	Sandy Loam	Blackleg (other than basal)	1.7	0.2
2000	Sandy Loam	Aster Yellows	2.0	0.2
2000	Clay	Basal Sclerotinia	4.0	0.4
2000	Clay	Sclerotinia (other than basal)	30.0	1.2
2000	Clay	Basal Blackleg	2.9	0.3
2000	Clay	Blackleg (other than basal)	4.6	0.4
2000	Clay	Aster Yellows	2.0	0.3
2000	Clay Loam	Basal Sclerotinia	0.9	0.1
2000	Clay Loam	Sclerotinia (other than basal)	7.9	0.5
2000	Clay Loam	Basal Blackleg	8.3	0.6
2000	Clay Loam	Blackleg (other than basal)	10.6	0.6
2000	Clay Loam	Aster Yellows	1.8	0.2

Canola stem diseases were at low levels overall, but Exceed was infected more than Invigor. This difference may have slightly biased yield data. There was no trend for

disease occurrence and seeding rate even though increasing seeding rate has been associated with higher disease occurrence due to crop canopies closing sooner and creating more suitable growth conditions for fungal pathogens to thrive in (Turkington & Morrall, 1993). Full canopy closure occurred even at low planting densities, and due to moist growing conditions during 1999 and 2000, the gradient of canopy humidity between planting densities was likely small. Nelson et al (1989) also found no consistent relationship between plant population and sclerotinia infestation in sunflowers, concluding disease progress was related more to inoculum density. Overall, disease pressure was light and uniform so with the possible exception of culitivar differences, any influence on yield was small.

Canola Yield and Volunteer Barley Dockage

Canola yield is a measure of production success. The relative yield of canola grown with and without weeds indicates the competitiveness of the crop. Moreover, how seeding rate, cultivar or seed treatment affects this relationship provides insight into the potential impact of these treatments on canola's competitiveness. Net return is an important factor, so if inputs provide a benefit only during the early stages of crop development but not for yield, their use may not be justified.

Cultivar was the most important factor contributing to canola yield, accounting for 18-35% of the total variance relative to 12-24% for seeding rate and only 1-4% for seed treatment (Table 37). The presence or absence of weeds contributed 8-43% of the variance, suggesting weed competition was in some instances the primary yield determinant (Table 37). Invigor canola yielded more than Exceed canola in all cases, both when weeds were and were not present (Figures 27-31). Furthermore, Invigor plots

without weed control yielded similar to (Figures 29&31) or greater than (Figure 30) Exceed plots with weed control and the difference between weedy and weed free plots was smaller for Invigor relative to Exceed (Figure 27-31), suggesting Invigor is more competitive.

For both cultivars, increasing seeding rate beyond approximately 100 plants/m^2 resulted in only minor yield increases (Figures 27-31). When averaged over seeding rate, canola treated with the mixture of thiamethoxam, difenoconazole, fludioxonil, and metalaxyl-M yielded higher than the non treated control at 4 of 5 sites (Table 39). Canola treated with the mixture of thiamethoxam, difenoconazole, fludioxonil, and metalaxyl-M yielded higher than canola treated with the mixture of lindane, carbathiin, and thiram at 3 of 5 sites, and higher than canola treated with the mixture of lindane, carbathiin, and thiram plus terbufos at 2 of 5 sites. Overall, cultivar was the primary factor affecting yield, with seeding rate influencing yield among culitivars to a greater extent than seed treatment.

Cultivar differences in yield were not surprising considering the difference in genetic potential, however; the greater yielding capability of Invigor relative to Exceed when weeds were present suggests it was more competitive. The plateau response of canola yield to seeding rate demonstrates the regulation effect of intraspecific competition on potential yield. The low impact of seed treatment suggests damage caused by flea beetles early in development, though relatively high in some cases, was still relatively inconsequential.

Table 37: Contribution of Cultivar, the presence/absence of weeds, seeding rate, and seed treatment to total variation for canola yield

	1999 Clay			1999 Sandy Loam			2000 Sandy Loam			2000 Clay			2000 Clay Loam		
Source	df	% total	Signif.[a]	df	% total	Signif.	df	% total	Signif.	df	% total	Signif.	df	% total	Signif.
Error	189	15.1	-	189	25.8	-	189	10.3	-	141	13.7	-	189	21.6	-
Replication	3	3.7	***	3	8.4	***	3	1.5	***	3	5.9	***	3	4.2	***
Cultivar	1	17.8	***	1	23.5	***	1	34.7	***	1	35.2	***	1	25.0	***
Presence/Absence of Weeds	1	43.3	***	1	9.0	***	1	25.4	***	1	8.3	***	1	29.3	***
Seeding Rate	3	11.5	***	3	22.8	***	3	18.9	***	3	24.0	***	3	11.5	***
Seed Treatment	3	1.4	***	3	2.8	***	3	4.2	***	3	2.6	***	3	0.5	NS

[a]Signif. = Significance

*,**,***Significant at p = 0.05, p = 0.01, and p = 0.001, respectively; NS, not significant

Table 38: Effect of seed treatment on canola yield averaged over cultivar and seeding rate.

Year	Site	Seed Treatment	Mean	Std Error	LSD (p<0.05)/location
1999	Clay	Helix	984.6	65.1	a
1999	Clay	Vitavax RS	967.4	62.0	a
1999	Clay	Vitavax RS & Counter	999.1	66.8	a
1999	Clay	None	846.5	65.7	b
1999	Sandy loam	Helix	1843.1	53.7	a
1999	Sandy loam	Vitavax RS	1672.5	49.1	b
1999	Sandy loam	Vitavax RS & Counter	1754.6	53.7	b
1999	Sandy loam	None	1680.0	47.0	b
2000	Sandy loam	Helix	1580.7	65.3	a
2000	Sandy loam	Vitavax RS	1477.5	66.2	b
2000	Sandy loam	Vitavax RS & Counter	1594.1	64.6	a
2000	Sandy loam	None	1327.9	60.4	c
2000	*Clay*	*Helix*	*1761.3*	*40.0*	*a*
2000	*Clay*	*Vitavax RS*	*1586.2*	*39.5*	*bc*
2000	*Clay*	*Vitavax RS & Counter*	*1648.6*	*36.6*	*b*
2000	*Clay*	*None*	*1496.1*	*35.9*	*c*
2000	Clay loam	Helix	1749.4	63.3	a
2000	Clay loam	Vitavax RS	1685.3	56.9	a
2000	Clay loam	Vitavax RS & Counter	1678.0	63.9	a
2000	Clay loam	None	1658.9	53.6	a

Note: 2000 clay site comparisons were done using least square means due to unbalanced data.

Table 39:Initial slope and asymptote coefficients for canola yield at the 1999 clay site.

Parameter	Parameter Estimate	Std. Error	R-squared
Initial slope_Invigor	113.83	19.38	0.768953
Initial slope_Invigor with weeds	25.89	5.50	
Initial slope_Exceed	59.00	11.90	
Initial slope_Exceed with weeds	22.74	9.52	
Asymptote_Invigor	2025.64	93.87	
Asymptote_Invigor with weeds	1452.04	220.24	
Asymptote_Exceed	1473.53	115.60	
Asymptote_Exceed with weeds	705.96	141.21	

Table 40: Initial slope and asymptote comparisons for canola yield at the 1999 sandy loam site.

Parameter	Parameter Estimate	Std. Error	R-squared
Initial slope	279.30	41.94	0.469636
Asymptote_Invigor	2293.61	57.67	
Asymptote_Invigor with weeds	2021.15	53.31	
Asymptote_Exceed	1891.39	53.83	
Asymptote_Exceed with weeds	1559.99	47.98	

Table 41: Initial slope and asymptote comparisons for canola yield at the 2000 sandy loam site.

Parameter	Parameter Estimate	Std. Error	R-squared
Initial slope_Invigor	284.01	48.94	0.771797
Initial slope_Invigor with weeds	144.37	25.17	
Initial slope_Exceed	138.83	14.79	
Initial slope_Exceed with weeds	60.33	51.82	
Asymptote_Invigor	2325.89	56.09	
Asymptote_Invigor with weeds	1911.16	73.29	
Asymptote_Exceed	1899.29	59.24	
Asymptote_Exceed with weeds	1324.06	222.34	

Table 42: Initial slope and asymptote comparisons for canola yield at the 2000 clay site.

Parameter	Parameter Estimate	Std. Error	R-squared
Initial slope_Invigor	161.35	33.47	0.735612
Initial slope_Invigor with weeds	98.03	78.78	
Initial slope_Exceed	88.67	25.83	
Initial slope_Exceed with weeds	60.68	8.73	
Asymptote_Invigor	2675.52	110.68	
Asymptote_Invigor with weeds	2510.37	248.56	
Asymptote_Exceed	2077.12	172.54	
Asymptote_Exceed with weeds	1694.00	100.98	

Table 43: Initial slope and asymptote comparisons for canola yield at the 2000 clay loam site.

Parameter	Parameter Estimate	Std. Error	R-squared
Initial slope_Invigor	420.62	98.41	0.682709
Initial slope_Invigor with weeds	230.53	52.53	
Initial slope_Exceed	265.98	73.47	
Initial slope_Exceed with weeds	101.68	23.73	
Asymptote_Invigor	2406.87	63.22	
Asymptote_Invigor with weeds	1929.44	67.83	
Asymptote_Exceed	1931.65	69.40	
Asymptote_Exceed with weeds	1505.15	85.92	

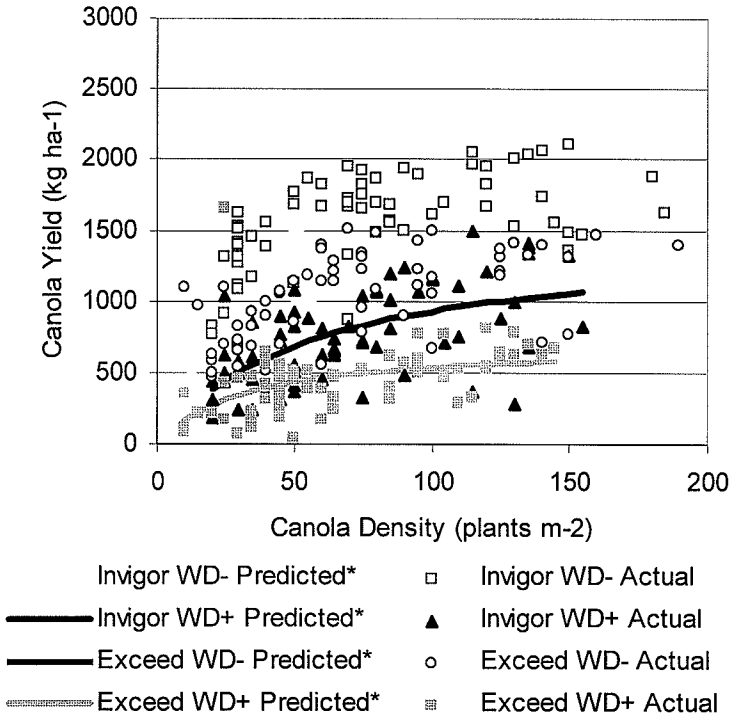


Figure 27: Canola Yield for the 1999 clay site. For coefficient values see Table 39.
WD+ = volunteer barley present
WD- = weed control
*Model used for predicted values based on equation from O'Donovan (1988)

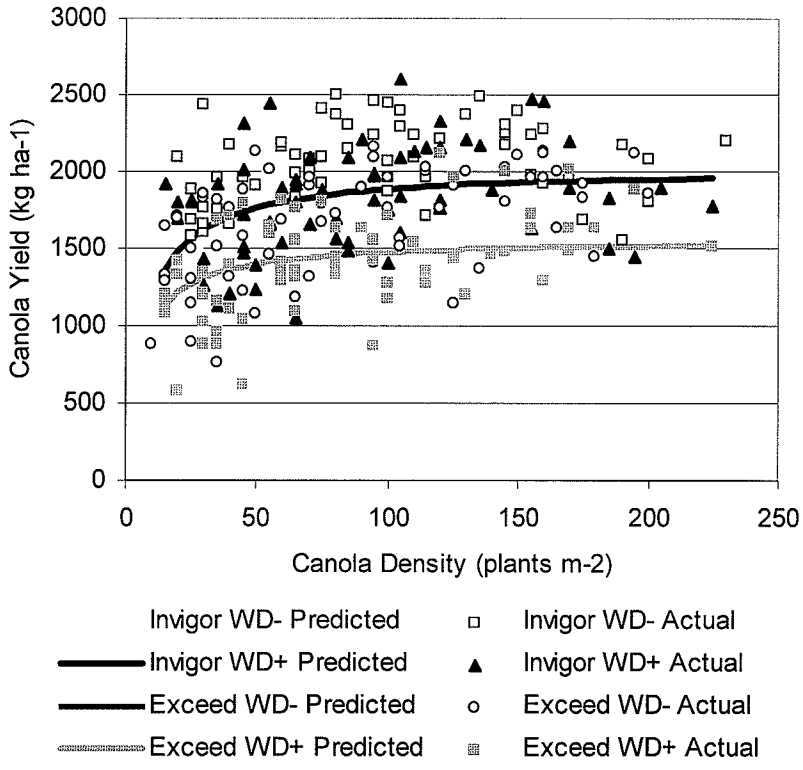


Figure 28:Canola Yield for the 1999 sandy loam site. For coefficient values see Table 40.
WD+ = volunteer barley present
WD- = weed control
*Model used for predicted values based on equation from O'Donovan (1988)

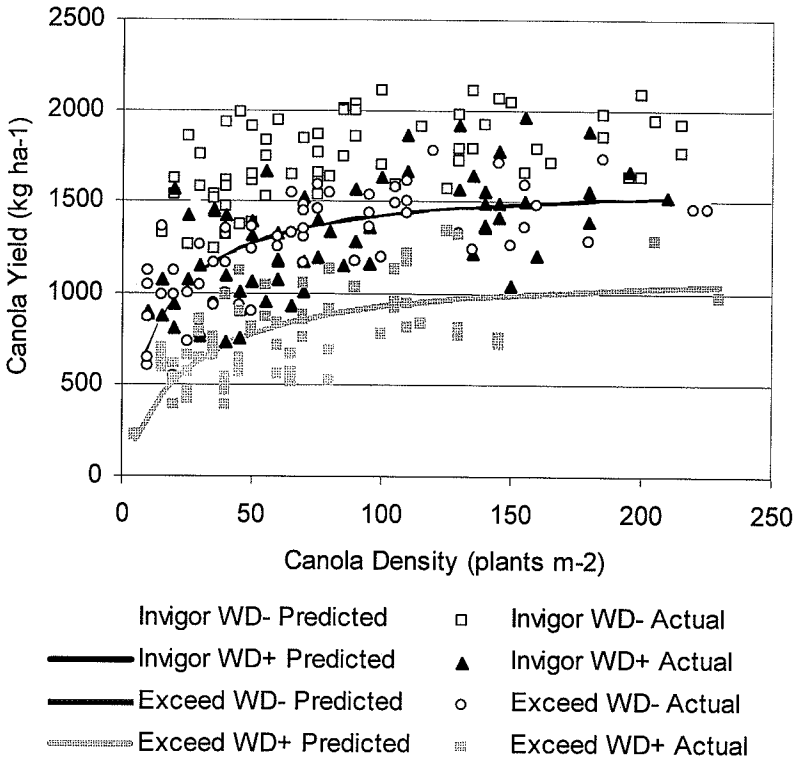


Figure 29: Canola yield at the 2000 sandy loam site. For coefficient values see Table 41.
WD+ = volunteer barley present
WD- = weed control
*Model used for predicted values based on equation from O'Donovan (1988)

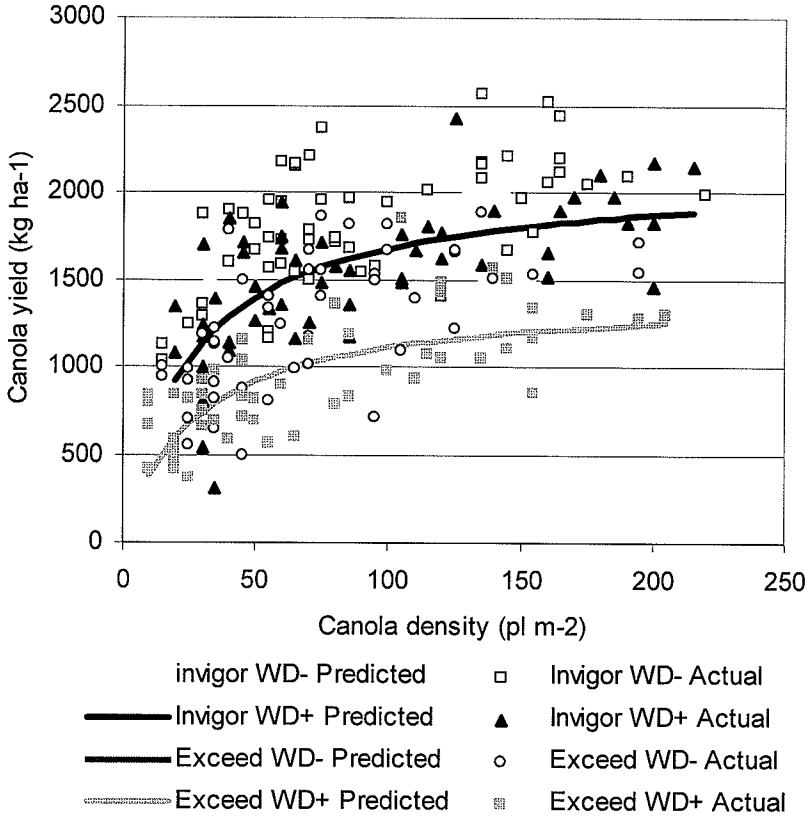


Figure 30: Canola yield for the 2000 clay site. For coefficient values see Table 43.
WD+ = volunteer barley present
WD- = weed control
*Model used for predicted values based on equation from O'Donovan (1988)

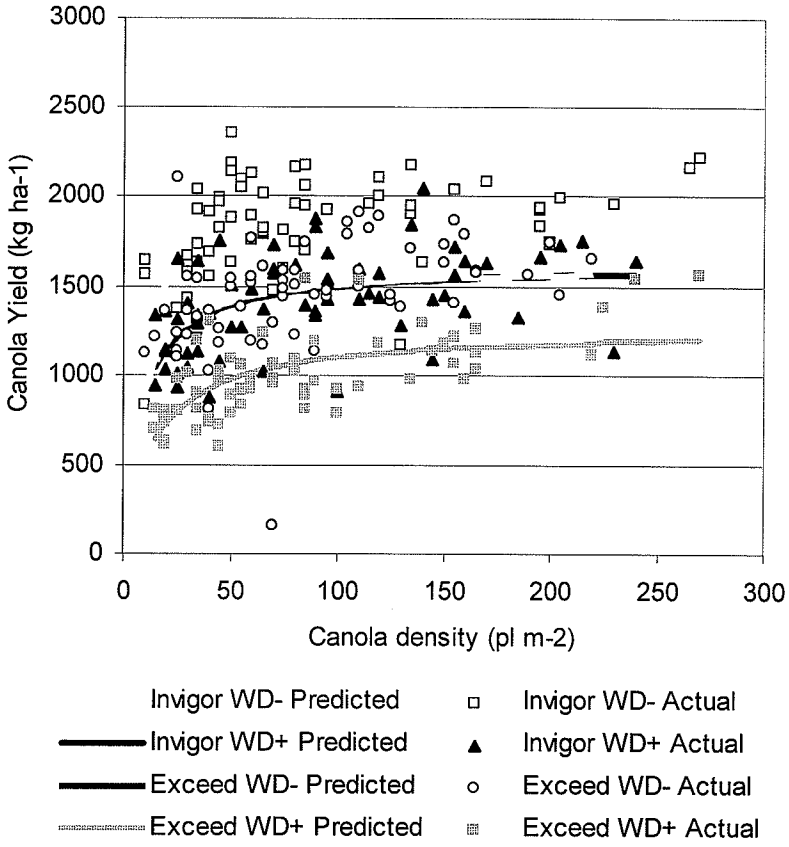


Figure 31: Canola yield for the 2000 clay loam site. For coefficient values see Table 43.
WD+ = volunteer barley present
WD- = weed control
*Model used for predicted values based on equation from O'Donovan (1988)

Volunteer barley dockage was measured to supplement canola yield data in determining relative weed suppression. Any positive effect cultivar, seeding rate, and seed treatment have on canola growth may translate into increased weed competition. Reducing weed growth is important for reducing yield losses and minimizing weed seed return.

Volunteer barley dockage was affected by experimental factors at only 3 of 5 sites. The 1999 clay and 2000 clay loam sites were unaffected, possibly because of extra weed pressure resulting from spray damage at the 1999 clay site which stunted canola growth and extra volunteer barley from the previous year at the 2000 clay loam site. At the three sites where dockage was affected by experimental factors, seeding rate had the most influence on volunteer barley dockage, accounting for 16-46% of the total variance. Cultivar and seed treatment accounted for 11-23% and 1-8%, respectfully (Table 38). Increasing seeding rate decreased volunteer barley dockage, but at a decreasing rate. For example, doubling canola density at the 1999 sandy loam site from 50 to 100 plants m^{-2} decreased volunteer barley dockage by approximately 28%, but adding another 50 plants m^{-2} for a total of 150 plants m^{-2}, only resulted in a further 20% increase in volunteer barley suppression. Invigor canola decreased volunteer barley dockage by 23-36% relative to the Exceed variety at all three sites (Figure 32-35), demonstrating that greater competitiveness can lead to greater weed suppression. All seed treatments lowered dockage at the 1999 sandy loam site, and at the 2000 sandy loam site, with the mixture of thiamethoxam, difenoconazole, fludioxonil, and metalaxyl-M (Helix) and the mixture of lindane, carbathiin, and thiram plus terbufos (Vitavax RS & Counter) suppressing

volunteer barley dockage more than the non-treated control, and mixture of lindane, carbathiin, and thiram (Vitavax RS) (Table 48).

Relative to seed treatment, increasing the number of plants competing with weeds and using a more vigorous cultivar both had a stronger impact on weed suppression. Damage caused by flea beetles did not always impede canola's weed suppression ability. Considering the possible range of cultivar competitiveness and diminishing returns from increasing seeding rate on weed suppression, optimum seeding rate may shift depending on cultivar vigor.

Table 48: The effect of seed treatment on barley dockage.

Year	Location	Seed Treatment	Mean (kg/ha)	Stderr	LSD (p>0.05)
1999	Sandy Loam	Helix	254.5	26.9	a
1999	Sandy Loam	Vitavax RS	284.7	22.0	a
1999	Sandy Loam	Vitavax RS & Counter	274.0	25.5	a
1999	Sandy Loam	Bare Seed	335.1	25.2	b
2000	Sandy Loam	Helix	667.9	47.9	a
2000	Sandy Loam	Vitavax RS	769.1	53.3	b
2000	Sandy Loam	Vitavax RS & Counter	640.2	44.9	a
2000	Sandy Loam	Bare Seed	823.4	38.9	b

Table 44: Contribution of Cultivar, seeding rate, and seed treatment to total variation for barley dockage.

	1999 Clay			1999 Sandy Loam			2000 Sandy Loam			2000 Clay			2000 Clay Loam		
Source	df	% total	Signif.[a]	df	% total	Signif.	df	% total	Signif.	df	% total	Signif.	df	% total	Signif.
Error	93	72.1	-	93	22.3	-	93	22.8	-	70	46.1	-	93	72.4	-
Replication	3	3.1	NS	3	1.4	NS	3	1.6	NS	3	6.8	*	3	0.9	NS
Cultivar	1	2.0	NS	1	19.0	***	1	22.6	***	1	11.1	***	1	<0.1	NS
Seeding Rate	3	4.2	NS	3	45.9	***	3	41.1	***	3	15.8	***	3	4.4	NS
Seed Treatment	3	3.0	NS	3	4.4	***	3	7.6	***	3	0.6	NS	3	3.3	NS

[a]Signif. = Significance

*,**,***Significant at p = 0.05, p = 0.01, and p = 0.001, respectively; NS, not significant

Table 45: Coefficients for barley dockage suppression at the 1999 sandy loam site.

Parameter	Parameter Estimate	Std. Error	R-squared
Intercept_Invigor	482.3617	81.9740	0.523603
Intercept_Exceed	598.6190	53.1256	
Slope_Invigor	0.0150	0.0055	
Slope_Exceed	0.0103	0.0025	

Table 46: Coefficients for barley dockage suppression at the 2000 sandy loam site.

Parameter	Parameter Estimate	Std. Error	R-squared
Intercept	1104.3595	49.5293	0.63073
Slope_Invigor with Helix	0.0161	0.0033	
Slope_Exceed with Helix	0.0067	0.0016	
Slope_Invigor with No Seed Treatment	0.0080	0.0018	
Slope_Exceed with No Seed Treatment	0.0036	0.0013	
Slope_Invigor with Vitavax RS	0.0107	0.0021	
Slope_Exceed with Vitavax RS	0.0025	0.0009	
Slope_Invigor with Vitavax RS & Counter	0.0152	0.0030	
Slope_Exceed with Vitavax RS & Counter	0.0084	0.0020	

Table 47: Coefficients for barley dockage at the 2000 clay site.

Parameter	Parameter Estimate	Std. Error	R-squared
Intercept	876.6403	52.8375	0.296784
Slope_Invigor	0.0065	0.0016	
Slope_Exceed	0.0021	0.0010	

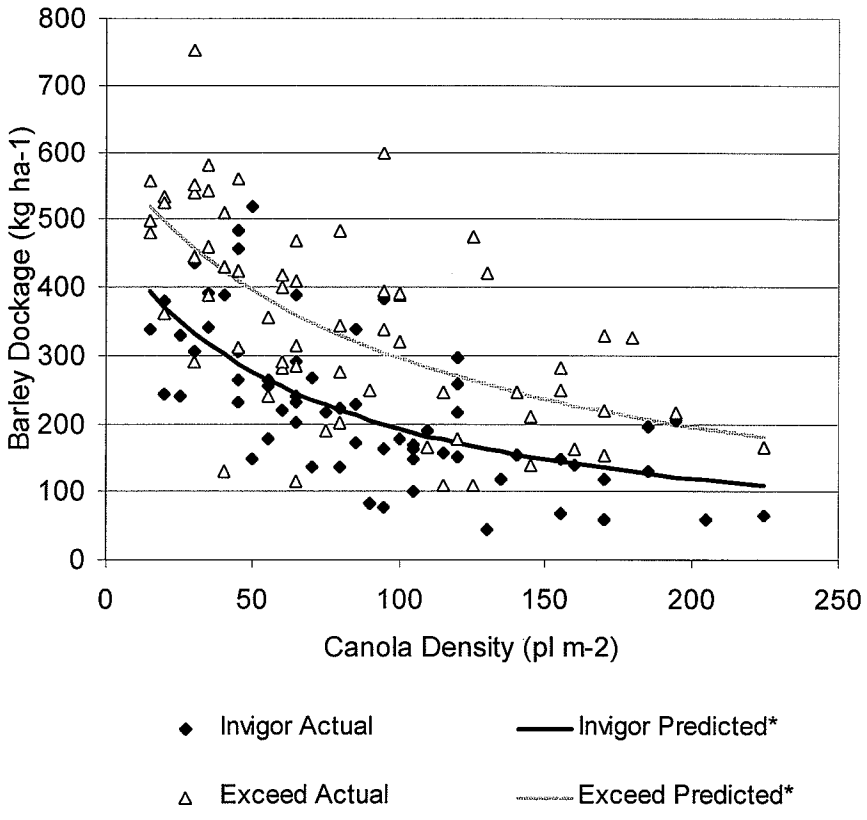


Figure 32: The effect of canola cultivar and density on barley dockage at the 1999 sandy loam site. For coefficient comparisions see Table 45. *Model used for predicted values based on modified equation from O'Donovan (1988)

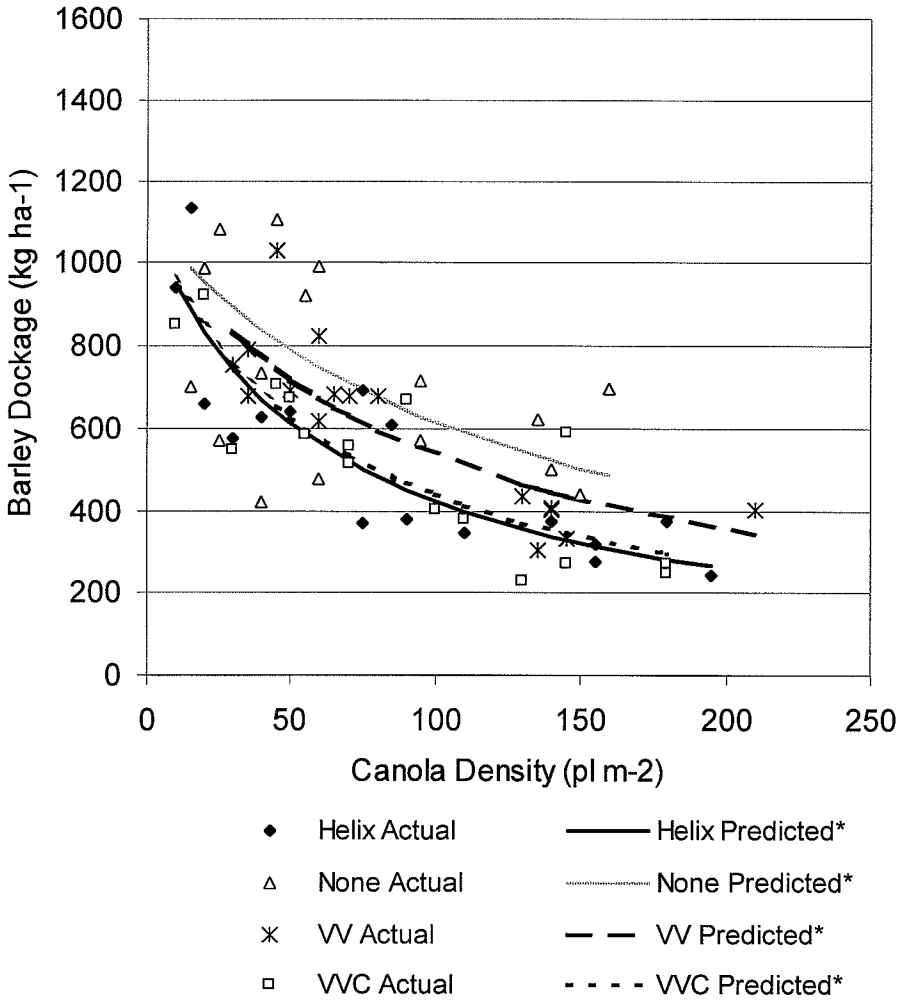


Figure 33: The effect of the Invigor variety, canola density, and seed treatment on barley dockage at the 2000 sandy loam site. For coefficient comparisions see Table 46.
Helix = thiamethoxam, difenoconazole, fludioxonil, & metalaxyl-M
None = bare seeed
Vitavax RS (VV) = lindane, carbathiin, & thiram
Vitavax RS & Counter (VVC) = lindane, carbathiin, & thiram plus terbufos
*Model used for predicted values based on modified equation from O'Donovan (1988)

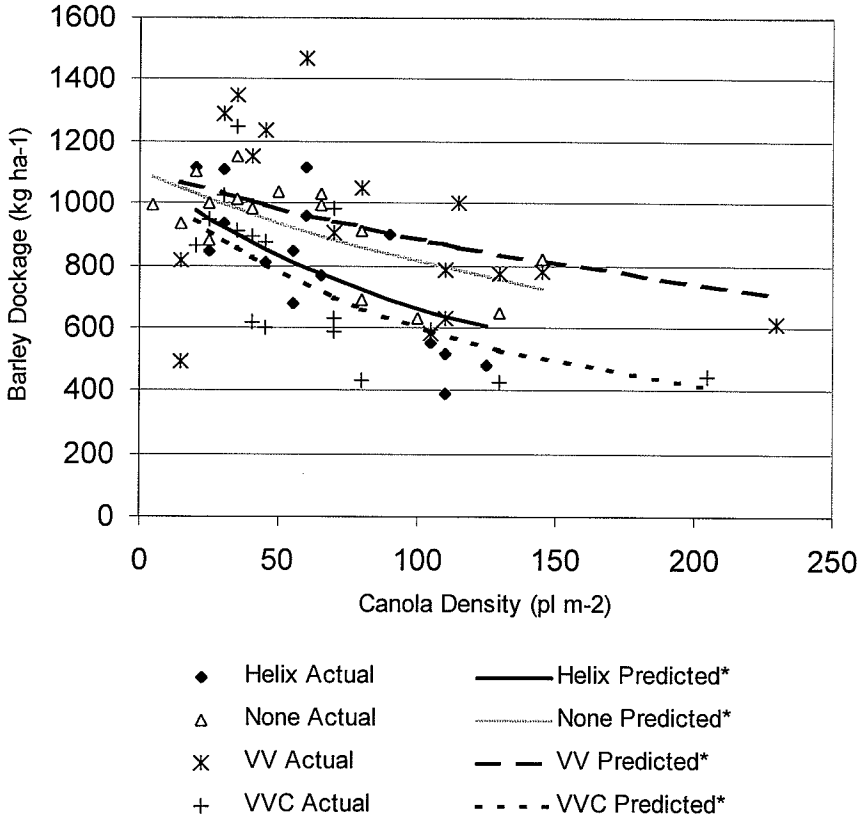


Figure 34: The effect of the Exceed variety, canola denstity, and seed treatment on barley dockage at the 2000 sandy loam site. (Vitavax RS (VV), Vitavax RS & Counter (VVC), No Seed Treatment (None)). For coefficient comparisions see Table 46.
Helix = thiamethoxam, difenoconazole, fludioxonil, & metalaxyl-M
None = bare seeed
Vitavax RS (VV) = lindane, carbathiin, & thiram
Vitavax RS & Counter (VVC) = lindane, carbathiin, & thiram plus terbufos
*Model used for predicted values based on modified equation from O'Donovan (1988)

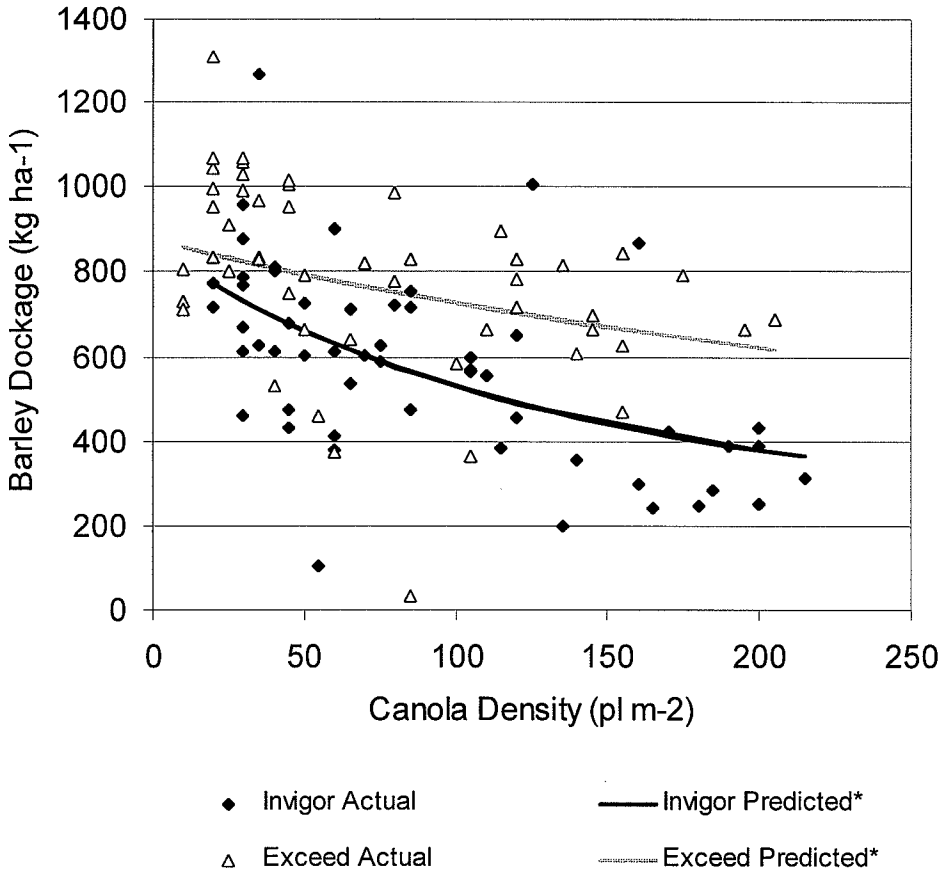


Figure 35: The effect of canola cultivar and density on barley dockage at the 2000 clay site. For coefficient comparisons see Table 47.
*Model used for predicted values based on modified equation from O'Donovan (1988)

Canola yield and barley dockage were influenced most by the presence/absence of weeds, cultivar, and seeding rate. The hybrid variety Invigor displayed a higher rate of space capture by covering the ground more quickly and accumulating more biomass. This attribute contributed to greater yield as well as more barley biomass and dockage suppression relative to the Exceed variety. Hybrid canolas are known to yield more than open pollinated varieties (Sernyk & Stefansson, 1982; Brandel & McVetty, 1990), but their weed suppression ability is not well documented. Corn hybrids differ in their ability to suppress weeds (Lindquist & Mortensen, 1998), so a generalization that all canola hybrids are equally aggressive is not prudent.

Canola yield reached a plateau as seeding rate increased, demonstrating the law of constant yield, and agreeing with work by Morrison et al (1990). Increasing seeding rate also increased the rate of space capture, in regards to the rate of ground cover. Consequently, barley dockage declined as canola density increased, supporting work by O=Donovan (1988).

Despite having less effect than seeding rate and cultivar, when averaged over all treatments, damage from flea beetles reduced canola yield in the range of 0-15%, which falls within the predicted annual national average loss of 10% (Lamb & Turnock, 1982), but also shows the high variability of yield loss associated with damage from flea beetles. This was also experienced by Putnam (1977) who found an apparent yield loss due to flea beetle feeding of 17%, but it was not statistically significant. Canola treated with a mixture of lindane, carbathiin, and thiram (Vitavax RS) yielded lower than when terbufos was added (Vitavax RS & Counter) or a mixture of thiamethoxam, difenoconazole, fluidioxonil, and metalaxyl-M (Helix) was used, supporting work by Braken & Baucher

(1986) showing yield decreases as the unprotected period increases. Furthermore, canola treated with a mixture of lindane, carbathiin, and thiram did not always yield higher than non treated canola and results from the greenhouse experiment suggests a possible growth inhibition by this seed treatment, which may contribute to this result.

Summary and Conclusions

Canola establishment was not greatly affected by seed treatment nor cultivar in the south western region of Manitoba most likely because soil borne pathogens affecting canola are at typically low levels. Further work examining the impact of fungal pathogens on canola competitiveness could be very useful for areas where soil borne pathogens levels are high. Information concerning any variation between cultivars in their ability to evade pathogens and it's impact on canola competitiveness may also prove very useful.

Seed treatment protected seedlings from flea beetle feeding but protection did not always translate into improved growth, weed suppression, or canola yield under near optimal growing conditions. In the absence of flea beetles, canola treated with a mixture of lindane, carbathiin, and thiram may be less competitive against barley than either untreated canola seed or canola seed treated with a mixture of thiamethoxam, difenconazole, fludioxonil, and metalaxyl-M. Seeding rate was the most influential factor affecting canola ground cover and all factors influenced canola biomass. The presence/absence of weeds, cultivar, and seeding rate affect canola yield more than seed treatment. Invigor yielded greater and was more competitive against weeds than Exceed. As seeding rate increased canola yield reached a plateau, but barley dockage continued to

decline. Seed treatment had no influence on barley biomass suppression and only influenced barley dockage at two of five locations.

The low impact of flea beetle feeding on canola yield and weed suppression relative to the effect of cultivar and seeding rate raises a few questions concerning weed competition and the impact flea beetles have on canola's vigor. The mere presence of a plant may be far more important than it's vigor for space capture during the early stages of development. Had plant vigor been important, treated canola would have had lower dockage and barley biomass relative to non treated canola, but this was not seen for either cultivar. The Invigor variety yielded more and suppressed barley greater than the Exceed variety, so vigor due to hetrosis may be more important for crop competitiveness than any added vigor due to protection from insects; however, since only two varieties were included more cultivars should be evaluated. Damage caused by flea beetles did not impact the mechanisms of competition, but this relationship may change when growing conditions are not favorable and stresses are compounded. Further study on the interaction between early insect stress and moisture or heat stress may prove useful for understanding the relative impact of early season canola growth on competitivess and yield.

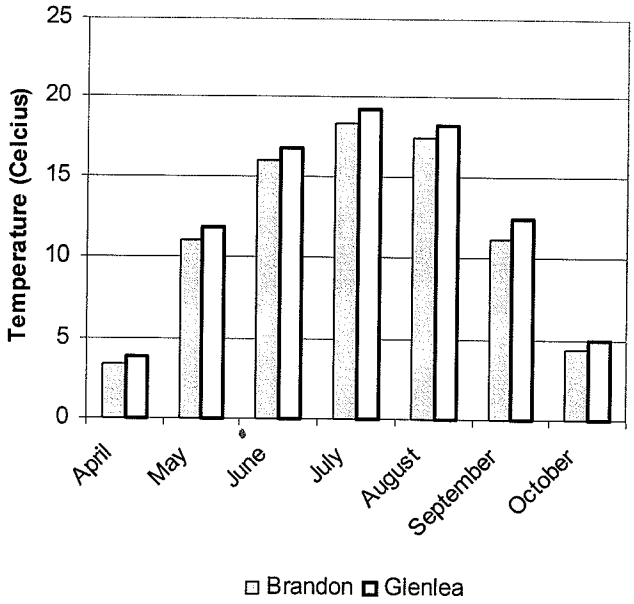
For producers, a low relative impact of seed treatment on canola competitiveness suggests that if a producer's weed problem is of greater urgency than their potential risk of flea beetle attack, input dollars may be better spent on a vigorous cultivar or increasing seeding rates. Certain hybrid cultivars may be more suitable for pesticide free production (Van Acker et al., 2000) than open pollinated varieties; however, the competitive potential of hybrids may not be equal, or change under certain environments.

Prophylactic use of seed treatment may be counter productive when the risk of flea beetle infestation is low and growing conditions optimal. If conditions are hot and dry, seed treatment becomes more important because both flea beetle and certain weed pressure will be greater. Under these conditions, thiamethoxam is a suitable replacement for lindane because of it's performance, but also because it is less harmful to both producer and environment. Finally, the economics of using a seed treatment with varying seeding rates and genetics under a range of environmental, flea beetle and weed pressure gradients should be examined since total cost rapidly increases as seeding rate increases.

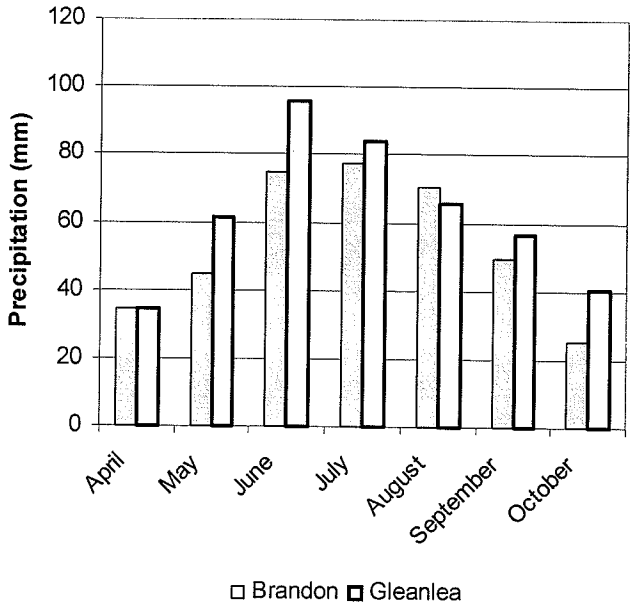
This thesis supports the notion that conducting integrated research is important for the evaluation of crop management practices. It was found that the benefits from inputs were not equal, therefore, more resources should be channeled into studies comparing the relative contribution of inputs. Utilizing all technology may reduce the risk of crop loss but, when benefits from inputs overlap financial risk unnecessarily increases. Therefore, providing producers with systems level information, gives them the opportunity to better manage inputs within the context of their production system and environment.

APPENDIX

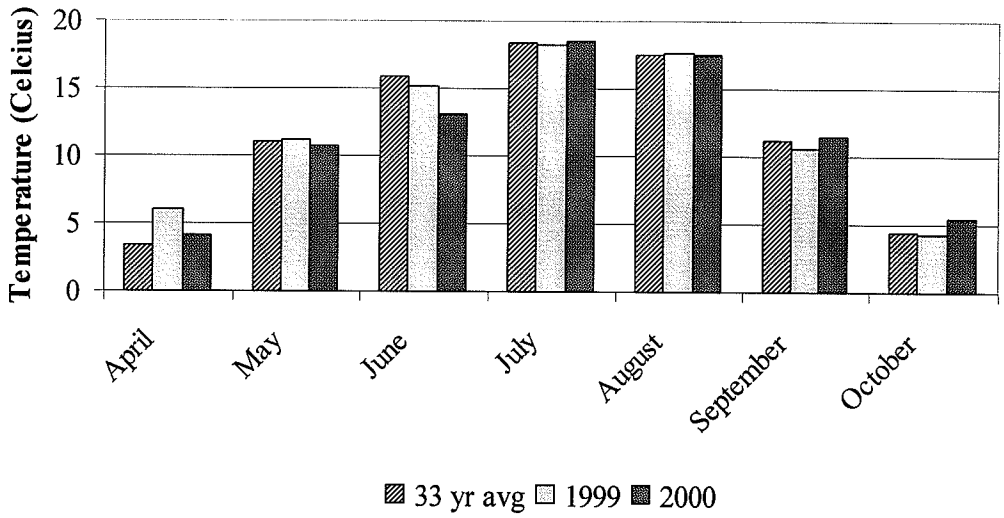
Average monthly temperature for Brandon and Glenlea, Manitoba.



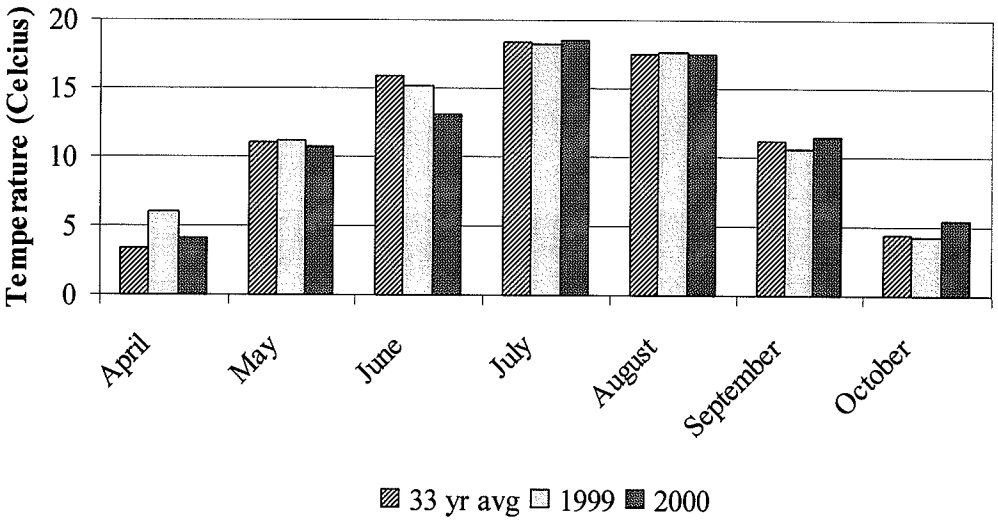
Average monthly precipitation for Brandon and Glenlea, Manitoba.



Average monthly temperature for 1999 and 2000 in Brandon, Manitoba, compared to the 33 year average.



Average monthly temperature for 1999 and 2000 in Brandon, Manitoba, compared to the 33 year average.



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