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INFLUENCE OF TILLAGE ON BLACKLEG AND OTHER DISEASES OF CANOLA GROWN IN ROTATION WITH BARLEY

CANOLA AGRONOMIC RESEARCH PROGRAM

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ABSTRACT

The effects of shortened canola rotations and reduced tillage on the severity of canola diseases were determined in a field experiment conducted near Viking, AB in 1996-2000. Test plots were laid out in a 3-cultivar × 2-tillage method × 4-rotation scheme factorial design. Two *Brassica napus* cultivars, Quantum (resistant to Blackleg) and Westar (highly susceptible to Blackleg), and one *B. rapa* cultivar, Reward (susceptible to Blackleg) were included in the test. Blackleg incidence in Quantum reached 87.9% in 1998, illustrating that genetic resistance cannot fully control Blackleg, but must be supplemented with crop rotation and other cultural control methods. Shorter crop rotations tended to result in more frequent transmission of *Leptosphaeria maculans* (the fungus that causes Blackleg) in seed. Root rot severity increased in conjunction with the frequency of canola crops in the rotation, but Alternaria black spot was largely unaffected. Low incidence of Sclerotinia stem rot prevented analysis in most years, but data collected in 1996 and 1997 suggest that Sclerotinia stem rot may become more severe when plants lodge in response to Blackleg infection.

In this study, reduced tillage (direct seeding through crop residues after deep-banding of fertilizer) was compared with conventional tillage (disking followed by two cultivator passes prior to seeding). Reduced tillage systems retain a large amount of potentially infected crop residues on the soil surface. The presence of these potentially infected residues on the soil surface did not increase the severity of any of the observed canola diseases. Moreover, disease progress data indicated that reduced tillage initially slows the rate of increase in Blackleg severity, although this difference disappears over time. Therefore, reduced tillage may be an effective method of reducing losses to Blackleg, but only if crops are harvested as early in the growing season as possible. Reduced tillage decreased the transmission of *L. maculans* via seed, but did not affect seed transmission of the three fungi that cause Alternaria black spot. In all three years analyzed, transmission of A. *brassicae* (the most pathogenic of the *Alternaria* species that cause Black spot) by *B. rapa* cv. Reward was greater than either of the *B. napus* cultivars.

To determine the effect of crop rotation, continuously grown canola was compared with one, two or three canola crops grown in rotation with barley over four years. Crop rotation increased canola seed yield, and did so most effectively in the Blackleg-susceptible cultivars. Both Quantum and Westar canola consistently yielded over 30 bushels per acre when grown once or twice over four years, but Westar yield decreased substantially when grown three or four years of four. Measurable yield losses due to short rotation interval were seen in Quantum.

Soil moisture treatments applied in growth chamber studies indicated that soil moisture does not significantly affect Blackleg severity, although maturation of infected plants progressed more rapidly if plants were moisture-stressed as well. This suggests that high levels of Blackleg can occur even in drier areas (such as southern Alberta), and that Blackleg infection may compound crop damage caused by drought. Neither cultivar nor rotation treatment significantly impacted the number of Blackleg and root rot propagules. Comparison of disease severity and incidence data with climate data revealed no relationships between soil temperature, soil water potential or precipitation.

INTRODUCTION

Reduced tillage is now a well-established cultural practice in western Canada. It conserves soil moisture through reduced evaporation and better water infiltration, and reduces wind and water erosion. Retention of crop residues on the soil surface can affect plant disease development by influencing the survival or activity of residue- or soil-borne pathogens. For example, the isolation frequency of *Leptosphaeria maculans* decreases rapidly when canola residue is buried, yet the pathogen can survive for long periods of time in the large residue pieces typical of reduced tillage systems, because survival is directly related to the rate of residue decomposition (1). Soybean residue has been found to harbour numerous fungi pathogenic to soybean, wheat and maize (2). Wheat residue infected with *Gaeumannomyces graminis*, the causal agent of Take-all, remains infective longer when on the soil surface than when buried (3). In wheat-fallow rotations, Crown rot of wheat severity was directly related to the amount of wheat residue on the soil surface (4).

Tillage methods and residue management also affect the status of soil biota, including organisms antagonistic to pathogens, and organisms that benefit crop plants directly. The hyperparasitic *Trichoderma* spp. increase in negative proportion to *L. maculans* in buried canola residue (1). Tillage has been shown to reduce total microbial biomass, fungal biomass and total soil fungal hyphae length compared to no-till control soils (5, 6, 7). Frey *et al.*(8) found that tillage reduces hyphal length in comparison to no-till systems, and also found that fungal biomass responds positively to increases in soil moisture, which bacterial biomass does not. Similarly, Harris *et al.*(9) found that tillage had no effect on the numbers of soil bacteria or nitrifiers. Most soil fungi are not plant pathogens, but rather are saprophytes and decomposers. Therefore, increased soil fungus populations should tend to decrease plant diseases in agroecosytems. For example, Take-all disease of wheat in the midwestern United States occurs less frequently in reduced tillage than in conventional tillage plots (10). Results from experiments conducted in east central Alberta indicate some suppression of foliar disease in barley in a no-till system (11). Information on new tillage systems on canola disease including Blackleg is limited. A trend toward reduced soil populations of *Rhizoctonia* sp. was observed under reduced till compared with conventional tillage (12). Pseudothecia and ascospores of *L. maculans* are most readily formed on buried canola stubble (13). An understanding of how changes in soil conditions affect disease development is needed to predict how different tillage systems may influence canola diseases.

Like tillage practices, rotational practices may have profound impacts on soil microflora and microfauna. Ryszkowski *et al.* (14) observed fauna, bacterial and actinomycete impoverishment, and enrichment in the number of crop pests, in continuous rye fields. They attributed some of the negative impacts of continuous cropping on toxic metabolite accumulation in the soil. Smiley *et al.* (4) found that disease severity in wheat-fallow or continuous wheat rotations was greater than in wheat-pea rotations, and this was due at least in part to soil microflora effects on pathogen survival and virulence.

With the development of several Blackleg resistant canola cultivars, interest by farmers in shortening rotation intervals has increased. However, limited information is available on how shorter rotation intervals will affect Blackleg and other diseases of canola. Most present day recommendations are based on experiences with similar diseases of other crops, usually in other countries. Continuous cropping of cereals has been shown to increase foliar diseases (15, 16). Duczek *et al.* (17) suggested that one year and two years between wheat crops is necessary to control Tan spot and Septoria leaf spot, respectively, and that barley should not be grown within two years of a previous barley crop in order to reduce losses to Scald and Net blotch. Hall and Sutton (18) showed that *Fusarium avenaceum* populations and Take-all incidence were positively correlated with frequency of grass or cereal in the rotation. Banniza *et al.* (19) reported that *Rhizoctonia solani* populations in paddy rice were not affected by crop rotation.

Due to the lack of specific information, it is urgent that the effects of tillage systems and crop rotations on canola diseases be determined, particularly in light of the development of Blackleg resistant canola cultivars. These cultivars may allow producers to seed canola more frequently than the currently-recommended four-year rotation. The purpose of this study was to generate information on whether farmers could safely adopt a shorter rotation without incurring disease losses. To address this need, experiments were started in Viking to determine the effects of shortened canola rotations on disease severity under reduced and conventional tillage systems.

OBJECTIVES OF THE STUDY

1. To determine the effect of reduced tillage and crop rotation on the severity of Blackleg, Seedling blight (root rot), Sclerotinia stem rot and Black spot of canola.
2. To detemine the effect of reduced-tillage on the survival and production of the sexual state of *L. maculans* in canola residues of *Brassica napus* and *B. rapa* cultivars.
3. To determine the effect of soil temperature and soil water potential on the survival of *L. maculans*.

MATERIALS AND METHODS

Field experiments were carried out at Viking, Alberta using plots established by the Agriculture and Agri-Food Canada in 1989. Test plots were laid out as a 3-cultivar × 2-tillage method × 4-rotation scheme factorial experiment with a split-split plot arrangement. Cultivar, tillage, and rotation were the main, sub- and sub-subplot factors, respectively, and each treatment was replicated four times (Figure 1). Two *Brassica napus* cultivars, Quantum and Westar, and one *B. rapa* cultivar, Reward were included in the test. The Canola Council of Canada rates Westar and Quantum as Highly Susceptible and Resistant to Blackleg, respectively, and Reward as Susceptible. Westco and Quantum were rotated with Lacombe barley, and Reward was rotated with Herrington barley. Tillage treatments consisted of conventional tillage (one pass with disk harrows, followed by two passes with a cultivator fitted with sweeps and spring harrows) and reduced tillage (no disturbance except for a fertilizer deep-banding pass prior to seeding). Crop rotations are detailed in Table 1. Nineteen hundred and ninety-five was considered a preparatory year, since all plots were seeded to Westar. Crop rotations were tested in 1996-1999, although comparison between all four rotations was possible only in 1999 since half the treatments were seeded with barley in 1996-1998 (Table 1).

Sub-subplot size was 9.25 × 6.00 m, with a 20-cm row spacing. Fertilizers (16-20-0-14, 11-51-0 and 34-5-0-0) were applied at seeding at rates determined by soil tests to obtain an available nitrogen rate of 100 lb per acre and a N: P: K: S ratio of 5:2.4:4:1. To ensure adequate levels of Blackleg disease, all plots were seeded with Westar in 1995, and Blackleg-infested canola stubble was spread on all plots in 1996, except those sown with Westar, which were sprayed with a suspension of *Leptosphaeria maculans* pycnidiospores ($1 \times 10^6 \bullet ml^{-1}$) applied at a rate of $0.8\ ml \bullet m^{-1}$ of row. Plots were not inoculated after 1996.

Plots were seeded in the third week of May in the years 1995 – 1999. In 2000, all plots were seeded with Invigor 2153 to examine the effects of the 1996-1997 cultivar, tillage and rotation treatments on a subsequent canola crop. Invigor 2153 was seeded either in fall (November 23, 1999) or in late spring (June 2, 2000). Tillage treatments were intended to remain the same as those used in previous years of the experiment, but the reduced tillage plots were inadvertently cultivated prior to seeding in 2000. Consequently, the data from the fall-seeded and spring-seeded plots were analyzed as separate experiments, since no comparison of reduced vs. conventional tillage was possible in the spring-seeded portion of the trial.

Table 1. Rotation treatments used at Viking AB, 1995-2000.

	Rotation scheme (treatments)			
Year	1 in 4	2 in 4	3 in 4	Continuous
1995 (all Westar)	Canola	Canola	Canola	Canola
1996	Barley	Barley	Canola	Canola
1997	Barley	Canola	Barley	Canola
1998	Barley	Barley	Canola	Canola
1999	Canola	Canola	Canola	Canola
2000 (all Invigor 2153)	Canola	Canola	Canola	Canola

Disease assessments

The impact of the experimental treatments on seedling blight was determined by counting the number of plants in two five-meter rows in each sub-sub plot 1996-1999. Emergence counts were conducted in the second week of June in 1996, 1997 and 1998, and in the last week of June in 1999.

The incidence and severity of Blackleg and Root rot were determined each year by randomly selecting fifty stems with roots attached from two five-meter rows per plot immediately after harvest. Harvest dates were September 30, 1996; September 17, 1997; September 14 (*B. rapa*) and October 1, 1998 (*B. napus*); and September 28, 1999. Severity of Alternaria black spot was determined each year by visually assessing 25 plants per plot for the percentage of pod area affected by the disease. Black spot evaluations were conducted on July 18-19, 1996; August 27, 1997, August 29-30, 1998; and September 15, 1999. Determinations of the percentage of affected tissue was aided by use of the severity scale developed by Conn *et. al* (20).

Severity of Blackleg and root rot were evaluated using the severity scales detailed in Table 2. Mean disease severity (MDS) was calculated for each plot on each date (equation 1); disease incidence was calculated as the number of plants in severity categories 1 through 5. The incidence of Sclerotinia stem rot-affected stems was also recorded, although low stem rot incidence precluded meaningful analysis in all years except 1996.

$$MDS = \sum iF_j / \sum F_i \quad \text{(Equation 1)}$$

where i and F_j are the severity categories and the frequency of plants in the jth severity category, respectively.

The increase in Blackleg severity and incidence in the 1 in 4 rotation was compared with continuous canola by examining Westar and Quantum plants several times in the 1999 growing season. Disease severity was estimated by rating 25 plants per plot on May 19, July 19, and August 6, 1999. Fifty plants were rated on September 28, 1999. MDS and disease incidence were calculated for each plot on each date. Assessments were not made in the 2 in 4 and 3 in 4 rotations. MDS and % incidence data were fitted to the logistic disease progress model (equation 2), by linearization with the logit transformation (equation 3) (21). The y-intercepts of the transformed curves were not significantly different from zero; logits were therefore fitted by zero-intercept linear regression ($y=rt$) using SAS-PROC REG Release 6.12 (SAS Institute, Cary, NC). This was done to ease comparison of proportional rates of infection (21).

$$\frac{dN}{dt} = rN\frac{K-N}{K} \qquad \text{(Equation 2)}$$

Where N=MDS or % incidence, and K= 5 (severity data) or 100 (incidence data), as appropriate; r is the proportional rate of infection. Where N=0, N+0.01 was substituted, and N was substituted with N-0.01 when MDS=5 or % incidence=100.

$$\ln(x/1-x) - \ln(x/1-x_o) = rt \quad \text{(Equation 3)}$$

Where $x=N/K$, which is the fraction of the host diseased at days from seeding t, $x_o=N/K$ at t=0 days, and r is the proportional rate of infection.

Seed yield

Yield was determined for each plot by weighing the seed after direct combining with a small plot combine, drying in a forced-air drier and hand cleaning. The harvested area of each plot was 12.21 m^2.

Seed transmission of *Alternaria* spp. and *Leptosphaeria maculans*

Sub-samples of seed harvested in 1997, 1998 and 1999 were retained for analysis of *L. maculans, Alternaria brassicae, A. brassicicola* and *A. raphani* seed transmission rates. Fifty (1997 and 1998) or 25 seeds per plot (1999) were surface sterilized in 1% NaHCl for 3 minutes, rinsed in sterile distilled water and transferred to 2% V-8 juice-rose bengal (V8RB=200 ml• ml^{-1}, V-8 juice, 50 mg•L^{-1} rose bengal and 3 g•L^{-1} $CaCO_3$, 200 ppm chloramphenicol and 200 ppm Streptomycin sulphate) in 100 x 15 mm Petri plates. Ten seeds were placed onto the V8RB agar in each plate. Plates were incubated at room temperature (ca. 21 °C) for 3-5 days, and then placed under near-UV fluorescent lighting for an additional 4-5 days to induce sporulation. Colonies were identified on the basis of morphology (22, 23).

Table 2. Blackleg and root rot severity rating scales.

Severity class	Description	
	Root rot	Blackleg
0	No disease.	No disease.
1	Trace surface discolouration of tap root.	Approx. ¼ of the stem circumference lesioned; lesion only superficial.
2	<50% of root surface area discolouration of tap root.	Approx. ½ of the stem circumference lesioned; may be some penetration of lesion.
3	50-95% discolouration of tap root.	Approx. ¾ of the stem circumference lesioned; significant penetration of lesion.
4	>95% discolouration of tap root, lateral roots severed.	Stem completely girdled but intact at the base; basal stem diameter normal; significant penetration.
5	Dead plant, or tap root severed below collar	Stem girdled at base, constricted, dry and brittle, may be completely severed; plant dead.

Effect of soil temperature and soil moisture on Blackleg and root rot of canola.

Environmental data were collected at the Viking site to determine the effect of soil temperature and soil moisture on severity of Blackleg and root rot of canola. A meteorological station in the northwest corner of the test site collected soil and air temperature, rainfall, solar radiation, and wind speed automatically by a Campbell Scientific Model CR10 data logger (Logan, Utah) throughout the growing season. Bi-hourly averages were calculated by the data logger from 1996-1999. Thermocouples and soil moisture sensors (Campbell Scientific model 253L) were installed in 1997 in all plots seeded with Reward canola to monitor soil temperature and soil moisture levels continuously; these data were averaged and recorded every hour. Rodent damage to the equipment caused occasional failures over the course of the study. Daily averages were calculated for all environmental variables prior to analysis.

Blackleg disease development at various soil moisture levels was measured in a growth chamber experiment. All plants (*B. napus* cv. Westar) were inoculated with Blackleg pathogen at uniform soil moisture potential (ψ_w) of -0.2 bars 24 h prior to application of moisture treatments. Plants were lightly wounded, in the midrib of the first and second true leaves and the first internode, with a bundle of insect pins then sprayed with a pynidiospore suspension (ca. 10 ml 1 x 10^6 spore/ml^{-1}). Non-inoculated control plants were wounded but not sprayed with the pycnidiospore suspension. Plants were at Harper-Berkenkamp growth stage 1.3 to 1.4 at the time of inoculation (24). Inoculated plants were subjected to target ψ_ws of –5.0 bars (moisture stress), -3.0, -1.0 and –0.2 bars (field capacity). Actual ψ_ws were allowed to fluctuate between field capacity and the target ψ_ws to simulate natural soil moisture cycles. A Campbell Scientific Model CR10X data logger fitted with Model 253-L moisture probes and thermocouples monitored soil temperature and ψ_w throughout the experiment. The data logger also controlled the addition of water to the growing plants automatically via solenoid-controlled valves. The experiment was conducted at temperatures of 20 and 17 °C (day/night) with a 16-hour day. All plants were individually rated for Blackleg MDS at 7 day intervals. The experiment was stopped when the most severely-affected plants reached an MDS of 5.

RESULTS AND DISCUSSION

Effect of crop rotation and tillage method on the severity and incidence of Blackleg of canola

Crop rotation effectively reduced Blackleg disease severity throughout the course of this study. In 1999, incidence and severity of Blackleg increased sharply as canola cropping frequency increased, particularly in the Blackleg-susceptible cultivars Westar and Reward (Figure 2). Crop rotation also significantly reduced Blackleg disease severity in 1997 and 1998 (Table 3), and had similar effects on disease incidence. Severity in Westar canola reached a maximum when grown three times in four years or more. Disease incidence data trends were similar to those of severity (Figure 2), and also reached high percentages quickly in a resistant cultivar. These results contradict those of Bailey *et al.* (25) who found that crop rotation did not reduce incidence of Blackleg. However, Blackleg levels in that study may have been too low to allow measurements of rotation effects on disease levels.

Although they were lowest in Quantum, Blackleg severity and incidence both increased when Quantum canola was planted more frequently (Figure 2, Table 3). For example incidence of Blackleg in Quantum reached 87.9% in 1998. Figure 2 suggests that disease severity in Quantum canola might have increased further if grown continuously for five years or more. This elevation in Blackleg levels would not have been seen on Quantum if genetic resistance had completely controlled the disease, indicating that genetic resistance cannot entirely prevent Blackleg. Resistant cultivars are not substitutes for crop rotation because genetic resistance cannot be relied on to eliminate the possibility of yield losses to the disease. High levels of Blackleg severity are possible if even resistant cultivars are grown continuously over long periods.

Tillage method had a negligible effect on Blackleg of canola, although reduced tillage slightly decreased the severity of Blackleg in 1999 (Appendix 1). The mean severity in the reduced tillage plots in 1999 was 1.5 on the 0-5 WCC/RRC scale (standard error = 0.06), whereas mean severity under conventional tillage was 1.8 (standard error = 0.06). This reduction occurred in all three cultivars (see non-significant cultivar × tillage term, Appendix 1). Significant reductions in Blackleg severity could only be attributed to reduced tillage in 1999; significant reductions due to tillage method were not observed in any other years of the study. The presence of *L. maculans* in canola residue on the soil surface does not increase Blackleg severity when a reduced-tillage system is used, and may occasionally reduce the severity of the disease slightly.

Effect of crop rotation and tillage method on Blackleg disease progress

In 1998 data showed that Blackleg severity was lowest on Quantum (Table 4). The superior Blackleg resistance of this cultivar was evident in mid-July, when the plants were still flowering. Incidence of Blackleg was also significantly lower on Quantum during flowering, but had reached levels equal to Westar by harvest. Quantum is probably best described as a Blackleg tolerant cultivar. That is, Quantum can be infected by *L. maculans*, although symptom expression is substantially less than in Blackleg-susceptible cultivars. Our results illustrate this point, since extremely high infection rates (disease incidence) coupled with low mean disease severity was observed in Quantum.

More detailed data collected in 1999 show that incidence (Figures 3 and 4) and severity of Blackleg (Figures 5 and 6) on continuously grown Westar regardless of tillage practice, advanced more rapidly and reached a higher level than in any other combination of tillage treatment and rotation. Over the growing season, Blackleg incidence on continuously grown Westar advanced by approximately 14% per day. Disease severity in Quantum (both rotations) and in the 1 in 4 rotation of Westar increased between 8.4 and 9.6% daily. Disease severity increased by approximately 6% daily when Westar was grown continuously (Figures 5 and 6); the daily disease severity increase in the remaining treatment was between 4 and 5%.

The proportional rates of increase in severity and incidence of Blackleg were lowest when Quantum was grown using a 1 in 4 rotation. The proportional rates were approximately equal when Quantum was grown continuously, or when Westar was grown in the 1 in 4 rotation (Figures 3 to 6). This suggests that the levels of Blackleg control achievable via the use of a resistant cultivar or via long crop rotations are approximately equal.

Blackleg incidence (Figures 3 and 4) and severity (Figures 5 and 6) curves indicate that tillage method did not affect the overall rate of infection. The number of infected plants had reached a maximum by 80 days after seeding Westar in the 1 in 4 rotation when conventional tillage was used (Figs. 3 and 5). Under reduced tillage, maximum severity and incidence were not reached until harvest (Figs. 4 and 6). This phenomenon was not seen either when Quantum was grown using the 1 in 4 rotation, or when Westar was grown using a continuous rotation. Reduced tillage slows the rate of increase in Blackleg infection, but this effect may be mashed when a susceptible cultivar such as Westar is grown in a short rotation. Growing a resistant cultivar such as Quantum will also hide this reductive effect, since disease severity and incidence in this case were so low as to make the effect unimportant. Also, any reduction in Blackleg severity due to the use of reduced tillage will be lost if crops are not harvested in a timely fashion, since epidemics in the Westar plots (1 in 4 rotation) were equally affected by the harvest date (138 days from seeding), regardless of the tillage system used.

Table 3. Effect of crop rotation on Blackleg disease severity at Viking, Alberta in 1997 and 1998.

Cultivar	Mean disease severity (0-5)					
	1997			1998		
	Canola on barley (2 in 4)		Continuous	Canola on barley (3 in 4)		Continuous
Quantum	1.1	**	2.0	1.1	**	1.6
Westar	1.7	**	3.6	2.3	**	3.3
Reward	2.1	**	3.2	1.8	ns	1.8

[1]Mean disease severity, where 0=no disease and 5=dead plant.
[2]Means separated by ** are significantly different (α=0.01). Means separated by ns are not significantly different.

Table 4. Comparison of Blackleg severity and incidence in three canola cultivars at Viking AB on two dates in 1998.

Cultivar	July 13-14		Harvest	
	MDS[1]	Incidence[2]	MDS	Incidence
Quantum	0.1a[3]	8.2a	1.4a	87.9a
Westar	0.4b	21.7b	1.8b	88.7a
Reward	0.5b	28.5c	2.8c	97.0b

[1]Least-square mean disease severity, where 0=no disease and 5=dead plant.
[2]Least-square mean percentage of Blackleg-affected plants.
[3]Least-square means in a column with the same letter are not significantly different according to a Tukey's multiple range test (α=0.05).

Root rot and seedling blight

Throughout the course of this study, root rot severity increased in conjunction with the frequency of canola crops within the rotation. This was most apparent in Westar, but could also be seen in Quantum (Figures 7 and 8, Table 5). Figure 9 also shows that Westar was more severely affected by root rot than Quantum, since plant stands of Westar canola decreased more sharply in response to shortened rotations than do Quantum plant stands. This may be due to an increase in inoculum in the soil due to increased frequency of canola crops. Hwang *et al.* (26) found that *Rhizoctonia solani* AG-2, which is preferentially pathogenic to canola, was more common in canola fields than other AG groups. However, if this were the case, we would expect all cultivars to respond equally to shortened rotations, and not the differential response between Westar and Quantum seen in this study. Alternatively, *L. maculans* may be weakening plants, predisposing them to attack by soil-borne pathogens such as *R. solani.*

Tillage treatment had little effect on severity or incidence of root rot. Reduced tillage slightly reduced root rot disease severity in *B. napus* cultivars in 1997 (Figure 8) but not in any other year of the study. Conversely, reduced tillage caused a slightly increased root rot MDS in Reward canola in 1997 (mean disease severity=2.0 vs 2.5 under conventional tillage, on average). However, these effects were small and probably did not significantly impact seed yield.

Crop rotation did not have a significant effect on seedling emergence (Figure 9). Tillage method did not adversely affect seedling emergence in the first two years of the study, decreased emergence in reduced tillage plots in 1998 and 1999 (Fig. 10). Close observation of seedlings in the reduced tillage plots in those years suggests that accumulated crop residues, and not disease, inhibit seedling emergence (Table 6).

Table 5. Effect of crop rotation on root rot severity and incidence in three canola cultivars at Viking AB in 1998.

	MDS [1]			Incidence [2]		
Cultivar	3 in 4 [3]		Continuous	3 in 4		Continuous
Quantum	1.2a[4]	**	1.6a	75.3a	**	88.5a
Westar	1.6b	**	2.2b	92.0b	ns	99.3b
Reward	1.6b	ns	1.6a	92.0b	ns	92.5ab

[1] Mean disease severity, where 0=no disease and 5=dead plant.
[2] Percentage of affected plants.
[3] Three canola crops in four years.
[4] Means in a column with the same letter are not significantly different according to a Tukey's multiple range test (α=0.01). Means in a row separated by ** are significantly different (α=0.01). Means separated by ns are not significantly different.

Table 6. Comparison of crop residue accumulation under conventional and reduced tillage in three canola cultivars at Viking AB in 1998.

	Surface residues[1] (g per m^2)		
Cultivar	Conventional		Reduced
Quantum	135.1	** [2]	441.7
Westar	115.3	**	300.6
Reward	120.3	**	330.6

[1] All plant residues in a 1m x 15-cm area were collected from each plot, air-dried and weighed. Data presented here are expressed on a g per m^2 basis, and are the means of four replicates.
[2] Means in a row separated by ** are significantly different ($P < 0.01$).

Leaf diseases

The cool, moist conditions that prevailed in 1996 encouraged the development of Downy mildew. This disease is not normally of concern in western Canada, although it is important in Europe. The cultivars differed significantly in susceptibility to the disease. Westar leaves were more severely (P=0.0124) and more frequently (P=0.0185) affected than leaves of Quantum or Reward, which did not differ significantly from one another (Table 7). Tillage did not affect Downy mildew severity (P=0.1515) or incidence (P=0.4350). Mean disease severity did not vary significantly among specific combinations of cultivar and tillage method.

In 1997, most foliar disease symptoms in all cultivars were caused by *Alternaria* spp. Significant amounts of Downy mildew were not observed. Rotation with barley resulted in a slight but significant (P= 0.0134) reduction in affected leaf area of 2.1% over non-rotated plots (data not shown). The beneficial effect of rotation was most apparent in Reward, although the effect was not statistically significant due to a high degree of plot-to-plot variability.

Overall, leaf diseases affected Quantum less than the other two cultivars. This may be due to Quantum's genetic resistance to Blackleg (which also causes symptoms on leaves), or perhaps *L. maculans* infection predisposes canola plants to infection by other pathogens such as *Alternaria* spp.

Severity of leaf disease in conventionally tilled plots was higher than in reduced-tillage plots (data not shown), but this effect was not statistically significant.

Dry conditions, which prevailed for most of the 1998 season, resulted in very low levels of most foliar diseases. These low disease levels did not allow for meaningful analysis of the data. Leaf disease data were not collected in 1999.

Table 7. Effect of tillage on Downy mildew disease severity and incidence in three canola cultivars at Viking AB in 1996.

	Mean disease severity			Affected leaves (%)		
Cultivar	Conventional		Zero-tillage	Conventional		Zero-tillage
Quantum	1.18a[1]	ns[2]	1.23a	62.81a	**	66.56a
Reward	1.20a	ns	1.43a	69.69a	ns	73.13ab
Westar	1.90b	ns	2.08b	80.63b	ns	81.56b

[1]Means in a column with the same letter are not significantly different by Duncan's multiple range test (α=0.01).

[2]Means in a row separated by ns are not significantly different by Duncan's multiple range test (α=0.05). Means separated by ns are not significantly different.

Sclerotinia stem rot

In 1996, the frequency of Sclerotinia stem rot was greatest in plots sown to Westar canola in (Table 8), particularly under conventional tillage. Stem rot incidence was very low at Viking in all other years of the study, averaging 5.5% in 1997 and less than 1% in 1998 through 2000. The low incidence of stem rot in the last three years was most probably due to climactic factors. This low disease incidence contributed to a non-normal distribution that could not be transformed to normality, thereby precluding analysis of variance. Nevertheless, examination of the data from 1997 showed that disease incidence in the *B. napus* cultivars included in the test was substantially greater than in *B. rapa* cv. Reward (Figure 11). Crop canopies of the *B. napus* cultivars at Viking were denser than those of Reward; this may have resulted in elevated humidity within the *B. napus* canopies, leading to increased stem rot incidence. Lodging of Westar canola due to Blackleg may have further increased stem rot incidence in that cultivar. Further examination of the data failed to reveal any effects of tillage or crop rotation. This may also have been due to the low Sclerotinia stem rot disease pressure encountered in 1997.

Table 8. Effect of tillage on Sclerotinia stem rot in three canola cultivars at Viking AB in 1996.

	Affected stems (%)		
Cultivar	Conventional tillage		Reduced tillage
Quantum	2.19a[1]	ns[2]	3.73a
Reward	1.85a	*	6.56b
Westar	13.45b	*	5.58ab

[1] Means in a column with the same letter are not significantly different by Duncan's multiple range test ($\alpha=0.05$) performed on arcsine-transformed means. Back-transformed means are presented here.
[2] Means in a row separated by * are significantly different by Duncan's multiple range test ($\alpha=0.05$). Means separated by ns are not significantly different.

Alternaria Black spot

Our data support the long-standing observation that *B. rapa* is more severely affected by Alternaria black spot (ABS) than *B. napus*. Reward canola (*B. rapa*) was significantly and substantially more severely affected by ABS in 1996-1998 than the *B. napus* cultivars Quantum and Westar (Table 9). Also, our results suggest that there may be a positive correlation between Blackleg and ABS since the Blackleg-susceptible cultivar Westar was more severely affected by *Alternaria* spp. than was Quantum.

The effects of crop rotation and reduced tillage on ABS severity were slight, although crop rotation was the more important of the two factors. Rotation with barley significantly reduced ABS severity by 0.37 percent in Quantum in 1996, 2.3 percent in Westar in 1997, and by 4.6 percent points in Reward in 1998. Comparisons among all four rotation schemes in 1999 showed that ABS severity in Westar canola increased substantially when canola was grown three or four years out of four (Figure 12). This seems to suggest that crop rotation decreased the severity of ABS. However, the response of ABS severity to crop rotation may be a secondary effect of reduction in Blackleg severity. Figure 12 shows that the response of ABS severity to crop rotation was substantial in the Blackleg-susceptible cultivar Westar, but weak in the Blackleg-resistant cultivar Quantum. Infection by *L. maculans* may weaken the plants or cause premature senescence of pods, thereby allowing accelerated invasion by *Alternaria* spp., so the type of differential response to ABS observed in this study would be expected in situations where plants were subject to infection by both *L. maculans* and *Alternaria* spp. Consequently, controlling Blackleg by crop rotation or other methods may have the added advantage of also reducing the severity of ABS.

Of the factors included in this study, cultivar (and species) and weather had the most powerful effect on ABS severity. Reward *(B. rapa)* was clearly more susceptible than either of the two *B. napus* cultivars (Figure 12, Table 9). Environment had the most profound effect on black spot severity over the four years of this study. Rainfall was more frequent in 1997 than any other year of the study (Figure 1 to 18).

Reduced tillage caused a slight increase in ABS disease severity in Quantum in 1996 and 1997; no other adverse effects of reduced tillage were observed in this study. ABS is an aerially dispersed disease; therefore the amount of surface residue within a plot is not expected to have a strong effect on production of *Alternaria* conidiospores.

Table 9. Effect of tillage on Alternaria black spot disease severity of three canola cultivars at Viking AB in 1996, 1997 and 1998.

	Percent pod area affected (± standard error)		
Cultivar	1996	1997 [1]	1998
Quantum	1.3 ± 0.1 a [2]	6.1 ± 0.7 a	0.8 ± 0.1 a
Westar	1.3 ± 0.1 a	12.9 ± 1.5 b	5.7 ± 0.7 b
Reward	5.0 ± 0.6 b	40.8 ± 0.6 c	8.3 ± 0.9 c

[1] Analyses were performed on transformed data (ln (y+1)). Non-transformed means are presented here.

[2] Means in a column with the same letter are not significantly different by a Tukey's multiple range test (α=0.05).

Seed transmission of *Alternaria* spp. and *L. maculans*

In all three years analyzed, transmission of *A. brassicae* by *B. rapa* cv. Reward was greater than either of the *B. napus* cultivars (Figures 19 - 21). Westar transmitted *Alternaria raphani* more frequently in 1998 and 1999, but not in 1997. The preferential transmission of *A. brassicae* by *B. rapa* may be due to the greater susceptibility of this species to ABS, since more severe infections should give more opportunity for the fungus to infect the seed. Interestingly, the higher ABS severity levels seen in 1997 vs. the remaining three years of the study (Figure 13) were not reflected in high seed transmission rates in that year (Figure 19). Also, seed transmission rates of the two more saprophytic species (*A. brassicicola* and *A. raphani*) were highest in 1999, a year of relatively ABS severity. This suggests that the environmental factors controlling disease severity are different from those controlling seed transmission of ABS.

In many instances, reduced tillage decreased the transmission of *L. maculans* via seed. The most dramatic example of this was seen in Reward canola in 1998, when the percentage of infected seed from reduced-till plots was less than half that from conventionally tilled plots (Figure 22). Reduced tillage did not affect seed transmission of *Alternaria* spp. in a consistent manner. For example, seed borne *Alternaria* was more frequent in reduced tillage in 1997, but less frequent in 1999 (Figure 23).

Shorter crop rotations tended to result in more frequent transmission of *L. maculans* in seed (Figures 24 and 25), but did not affect transmission of *Alternaria* spp. (Figure 23).

Yield

Of the three factors included in this study, canola cultivar (and species) had the strongest effect on seed yield, since the *B. rapa* cultivar (Reward) produced lower yields than either of the *B. napus* cultivars, regardless of cropping frequency or tillage method (Figure 26). Crop rotation was the next most important factor. Both Quantum and Westar canola yielded over 30 bushels per acre when grown once or twice over four years, but Westar yield decreased substantially when grown three or four years of four. Quantum yield did not decrease to the same degree when rotations were shortened (Figure 26). Thus, crop rotation was most beneficial in the Blackleg-susceptible cultivars. Similar results were obtained in 1997, when yields of Westar and Reward canola were significantly improved by crop rotation. This was not the case for the yield of Quantum, even though both Blackleg and root rot MDSs increased with increasing cropping intensity. Westar and Reward yields also benefited from crop rotation in 1998, but in that year a significant yield benefit was also seen in Quantum. Average yield losses of 27.3 and 33.2% were recorded in Quantum and Westar plots in 1998 when continuous canola plots were compared to a rotation of three canola crops in four years (Table 10).

Overall, results of this study show that reduced tillage did not depress canola yields, and increased yields in some years. Comparison of the two tillage treatments in 1999 showed that reduced tillage did not reduce seed yield (Figure 26). A similar result was also obtained in 1996 and 1999 (data not shown). In 1998, a significant yield advantage was obtained when reduced tillage was used (Table 11).

Table 10. Effect of crop rotation on yield of three canola cultivars at Viking AB in 1998.

	Yield (bu/ac)[1]		
Cultivar	3 in 4		Continuous
Quantum	31.1c[2]	*[3]	22.6b
Westar	26.8b	*	17.9a
Reward	20.1a	ns	17.3a

[1] Mean seed yield per plot, bushels per acre. Harvested area of each plot was 12.21 m^2.

[2] Means in a column with the same letter are not significantly different at the 5% level.

[3] Means separated by * are significantly different according to t-tests performed at the 5% level. Means separated by ns are not significantly different.

Table 11. Effect of tillage method on yield of three canola cultivars at Viking AB in 1998.

	Yield (bu/ac)[1]		
Cultivar	Conventional		Reduced
Quantum	23.7a[2]	ns[3]	30.0b
Westar	22.4a	ns	22.4ab
Reward	18.9a	ns	18.6a

[1] Mean seed yield per plot, bushels per acre. Harvested area of each plot was 12.21 m^2.

[2] Means in a column with the same letter are not significantly different at the 5% level.

[3] Means separated by ns are not significantly different at the 5% level.

Effect of tillage and rotation on Blackleg and root rot propagules

In this study, cultivar and crop rotation were important determinants of disease severity and yield. For example, *L. maculans* infected Westar and Reward to a greater degree than Quantum, and Blackleg was more severe in short canola rotations. Presumably, higher levels of infection result in increased amounts of propagules the following year; this in turn may lead to elevated disease severity and incidence. Therefore, more Blackleg and other diseases would be expected in canola planted following a susceptible cultivar on a short rotation, than in a resistant cultivar on a long rotation. To test this hypothesis, all plots at the Viking site were seeded with Invigor 2153 (Moderately Susceptible to Blackleg).

Half of the plots were seeded in the fall of 1999, and the other half were seeded in the spring of 2000 to examine the effects of fall seeding on Blackleg and root rot of canola. Figure 27 shows that spring-seeded canola produced higher yields than fall-seeded canola, although late herbicide application probably resulted in high yield losses in the fall-seeded plots due to excess weed competition. Figures 28, 29 and 30 show that the frequency of canola crops preceding the 2000 crop year had little effect on the yield or severity of either root rot or Blackleg in the Invigor 2153 crop. Also, fall seeding did not increase or decrease the severity of either disease.

The tillage treatments applied in 1996-1999 were also applied in 2000 in the fall-seeded plots only. Tillage treatment had no effect on Blackleg severity, but reduced tillage tended to decrease the severity of root rot (Figure 31).

Effect of soil temperature and soil moisture on Blackleg and root rot of canola.

Effect of soil water potential on Blackleg disease development

Soil moisture treatments did not significantly affect Blackleg severity of inoculated Westar plants in the growth chamber experiment (Fig. 32). This suggests that high levels of Blackleg can occur even in drier areas (such as southern Alberta), given that sufficient moisture is available to *L. maculans* at the time of initial invasion of host plants. Once infected, however, maturation of infected plants progressed more rapidly in moisture-stressed plants (Fig. 32, -5 bars) than in non-stressed plants (Fig. 32, -0.2 to -4 bars). This result indicates that dry conditions may not limit Blackleg damage once infection has occurred; in fact, Blackleg infection may exacerbate crop damage caused by drought.

A small but significant number of non-inoculated Westar plants became infected during the course of the experiment; this was due to secondary spread of pycnidiospores from inoculated plants. The mean severity of these secondary infections was higher under wetter soil moisture conditions (Figure 32). While Blackleg severity may not be affected by soil moisture, these results suggest that plant-to-plant spread of *L. maculans* is more efficient when adequate moisture is available.

Climactic effects on Blackleg and root rot disease development

Figures 14–17 provide air temperature, relative humidity, precipitation and rainfall data for the Viking site from 1996 to 1999. Nineteen hundred and ninety-six and 1998 had the most frequent rainfall events and the greatest total amounts of precipitation. Comparison of Figures 14–17 with Figures 18–34 suggests that precipitation had little effect on soil water potential. Soil water potential data indicate that adequate amounts of moisture were available in 1996 and the latter part of 1999: 1998 was characterized by wet periods interspersed with periods of moisture stress (Fig 33A). In 1998, soil temperatures in reduced-tillage plots were cooler in continuous canola than in plots that had been rotated with barley (Figure 33D). Comparison of the root rot and Blackleg severity and incidence data in previous sections of this report with climate data reveals no obvious correlations between soil temperature, soil water potential or precipitation. This indicates that effects of crop rotation and tillage (where they occur) are due mostly to biotic, and not climactic, factors.

CONCLUSIONS

Good control of blackleg was attained at Viking with crop rotation throughout the course of this study. Conversely, Blackleg severity and incidence increased in all three cultivars as the interval between successive crops was decreased, even in the Blackleg-resistant cultivar Quantum. Blackleg incidence reached high levels (87.9% in Quantum in 1998) as a result of short rotations. Thus it appears that genetic resistance cannot fully control Blackleg, but must be supplemented with crop rotation and other cultural control methods. To compare the rates of increase in Blackleg severity and incidence in conventionally-tilled vs. reduced-tillage plots, Westar and Quantum plants were examined several times in the 1999 growing season. Reduced tillage slowed the rate of increase in Blackleg severity, although this difference disappeared over time. Therefore, reduced tillage may be an effective method of reducing losses to Blackleg, but only if crops are harvested as early as possible in the growing season.

Interactions between diseases were apparent, particularly interactions between Blackleg and root rot, and Blackleg and Alternaria black spot (ABS). Westar canola appeared to be more susceptible to both root rot and ABS than Quantum, yet neither cultivar carries any resistance to these diseases. Blackleg infection can predispose canola plants to infections by root rot and ABS pathogens, or at least increase severity.

Seed analysis gave a strong indication that growers can use reduced-tillage and crop rotation to decrease the amount of seed-borne Blackleg. This result is most important to growers who produce Certified Seed. Crop rotation or tillage had a consistent effect on ABS transmission, although we found that *B. rapa* preferentially transmits *Alternaria brassicae,* the most aggressive of the ABS pathogens.

Analysis of climactic data and growth chamber experiments indicated that most of the factors controlling canola disease severity are biotic and not climactic. The report, the factors that affect the severity of canola diseases are not wholly dependent on weather, but instead can be influenced by producers.

IMPLICATIONS OF THE STUDY

Crop growers are going through a difficult period in terms of crop selection. Prices of cereal crops are low, and special crops are quite new and require special knowledge for controlling weeds, harvesting and marketing. Canola prices are also low, and serious diseases such as Blackleg and Sclerotinia stem rot affect canola. In the past few years, however, the development of canola cultivars moderately tolerant to Blackleg has allowed farmers to plant canola more frequently (thereby shortening the rotation) when no other crop seems profitable. However, heavy economic losses could be incurred if other diseases such as Blackleg, Sclerotinia stem rot or Rhizoctonia seedling blight increase. Also, intensive cultivation of a cultivar resistant to the prevalent strains of Blackleg could lead to the development of new strains of virulent Blackleg. One purpose of this research was to determine the effect of reduced tillage on certain diseases. This study indicated that reduced tillage does not increase the severity of canola diseases. Farmers can therefore adopt reduced tillage systems without increasing the risk of losing yield to disease.

Reduced tillage is becoming popular on the prairies. The information generated by this project is the first of its kind in North America for canola, and demonstrates that reduced tillage does not adversely affect the development of Blackleg and other diseases of canola. Producers can therefore save energy costs, conserve soil moisture, and prevent soil erosion through the prudent use of reduced tillage. This will not only lead to sustainable agriculture and increase overall profits but will also improve the environment.

Results of our experiments to date also indicate that crop rotation has a strong impact on disease severity in general. The beneficial impact of rotation of canola with barley was reflected in the seed yield data. For example, in 1997 rotation with barley added the equivalent of 10.0 bu/ac to Reward and 13.2 bu/ac to Westar yields. Similar results were obtained in other years of the study. Moreover, we discovered a 27.3% yield loss when the Blackleg-tolerant cultivar Quantum was grown continuously for three years. All cultivars showed reductions in disease levels in response to longer rotations. Moreover, this study gives the first indication that economically significant yield losses due to disease can occur when genetically-resistant canola cultivars are grown in short rotations. Growers who adopt short rotations risk substantial yield losses, even if resistant cultivars are used.

PUBLICATIONS AND PRESENTATIONS ARISING FROM THE STUDY

- Open field days were held annually, 1996-1999.
- Ralph Lange presented annual results at Canola Industry Meetings in Edmonton (April and November) in 1996, 1997 and 1998. Results were also presented at the Saskatchewan Canola Industry meeting in Saskatoon in 1998.
- Kent MacDonald presented results at a producer meeting sponsored by Agricore (60-70 participants) in December 1998 and at the Super Canola Meeting in Vegreville on February 9, 1999.
- We have forwarded data summaries (on request) to a number of extension specialists in Alberta.
- Some of the findings from this study were included in a report presented by the Canola Council of Canada to the parliamentary committee on the crisis in farm incomes in 1999.
- Results were made available to Dr. Randy Kutcher of Agriculture and Agri-food Canada, who presented them to the Saskatchewan Soil Conservation Association in Humbolt, Saskatchewan on December 15, 1998.
- Progress reports have been submitted to Canola Council of Canada as well as Alberta Agricultural Research Institute's On Farm demo program (North east region).
- Newsletter, newspaper, and trade publications:

  Lange, R. M., and P. D. Kharbanda. 1999. Reduced tillage does not increase diseases in canola. *Seeding on the Edge (http://www.agric.gov.ab.ca/sustain/sote/)*, February issue.

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  Alberta Research Council Inc. Wednesday, August 4, 1999. Surprising results on canola will highlight field day.

- Results were presented at the Joint Annual Meeting of the American Phytopathological Society and the Canadian Phytopathological Society, Montréal, PQ, August 7-11, 1999:

  Lange, R. M., and P. D. Kharbanda. 1999. Effect of reduced tillage and crop rotation on canola diseases. Phytopathology 89, no. 6: S43.

- The full results of the study will be published in the Canadian Journal of Plant Pathology or the Canadian Journal of Plant Science.

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BIOGRAPHICAL DATA

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Kharbanda, Prem D.

Post-Secondary Education and Training Relevant to Proposal:

Institution	Field Specialization	Degree/Diploma	Year Completed
U.P. Agric. Univ., Pantnagar, India	Crop Protection	B.Sc. (Hons) Ag., & A.H.	1964
U.P. Agric. Univ., Pantnagar, India	Plant Pathology	M.Sc.	1966
Univ. of Illinois, Urbana, Illinois	Plant Pathology	Ph.D.	1971

Relevant Professional Experience (begin with present position):

Dates	Position or Function	Employer	Location
1981-Present	Plant Pathologist	Alberta Environmental Centre	Vegreville AB
1979-1981	Research Associate	Alberta Agriculture	AHRC, Brooks AB
1972-1979	Research Associate	University of Manitoba	Winnipeg
1968-1971	Graduate Research	University of Illinois	Urbana

Research Activities Related to Research Proposal (list up to 4 projects):

Title	Date
• Project Leader, Disease Management in Cereals, Oilseeds, and Turfgrass.	1981-Present
• Integrated management of Blackleg, seedling blight, and Sclerotinia stem rot of canola; biology of Leptosphaeria maculans; survey of Blackleg and other diseases of canola	1983 -present.
• Effect of tillage on diseases of barley and canola	1992 - present
• Biological control of canola diseases	1993 - present

Relevant Articles Published in Refereed Journals and Other Relevant Works

1. Kharbanda, P. D., and R. M. Lange. 1998. Influence of tillage on Blackleg and other diseases of canola grown in rotation with barley. Canola Council Project # 96-14. Report for the year 1997. Submitted to Alberta Canola Producers Commission, Saskatchewan Canola Development Commission, and Canola Council of Canada. February 1998. 23pp.
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Lange, Ralph Martin

Post-Secondary Education and Training Relevant to Proposal:

Institution	Field Specialization	Degree/Diploma	Year Completed
University of Alberta	Plant pathology	M. Sc. in Agriculture	1993
University of Alberta	General Agriculture	B. Sc. in Agriculture	1988

Relevant Professional Experience (begin with present position):

Dates	Position or Function	Employer	Location
May 1996-Present	Plant pathologist	Alberta Research Council	Vegreville
July 1993-May 1996	Plant pathologist	Alberta Agriculture, Food	Edmonton
May 1988-August 1989	Plant Breeding Technician	Pioneer Hi-Bred Ltd.and Bio-Technica Canada Ltd	Calgary

Research Activities Related to Research Proposal (list up to 4 projects):

Title	Date
Effect of tillage on diseases of canola and barley	1996-present
Integrated Pest Management in short rotation canola	1996-present
Screening of canola breeding lines for disease resistance	1988-1993 & 1996-present
Fungicidal control and epidemiology of Entomosporium leaf and berry spot of saskatoon.	1993-1996

Relevant Articles Published in Refereed Journals and Other Relevant Works

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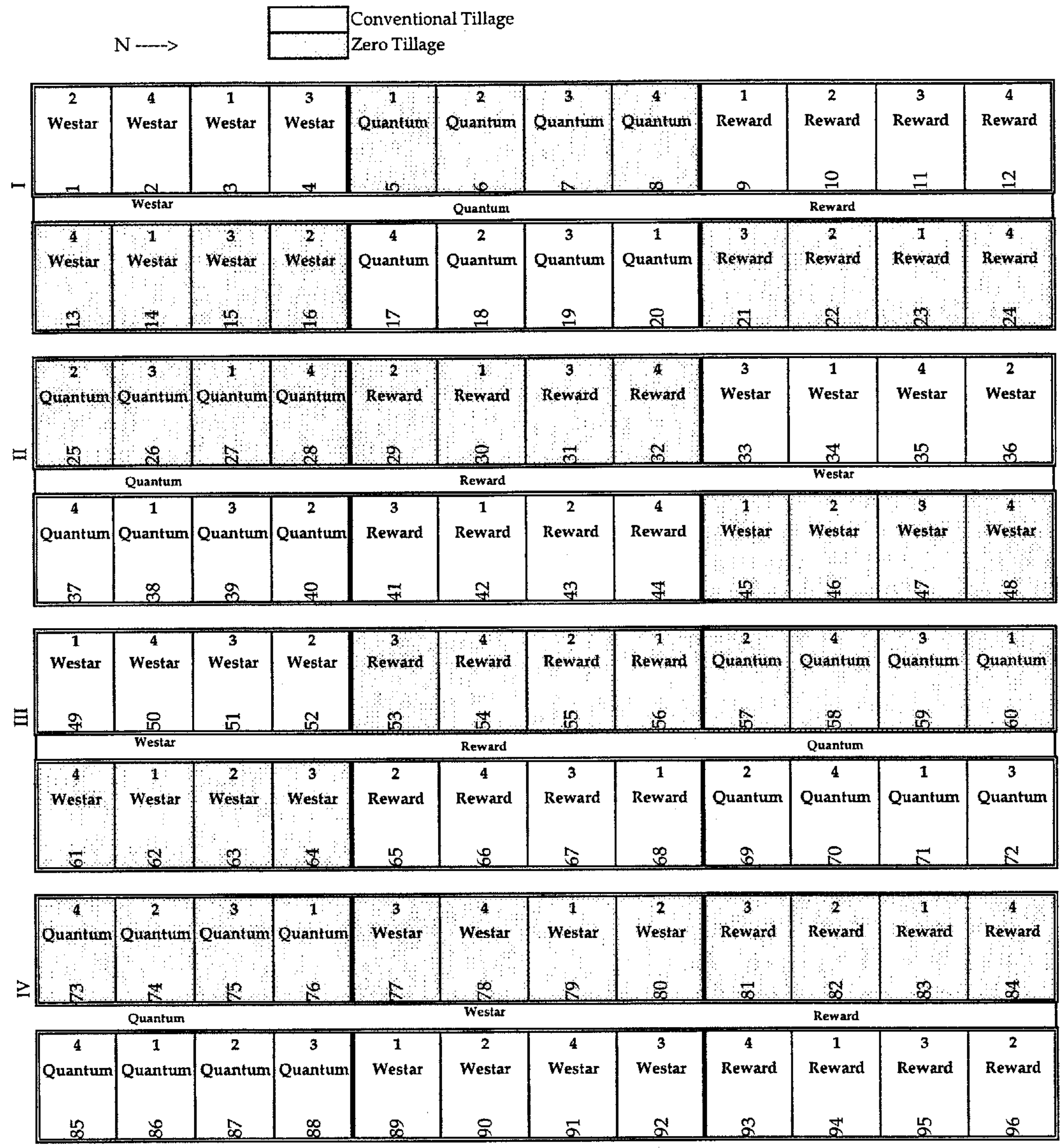
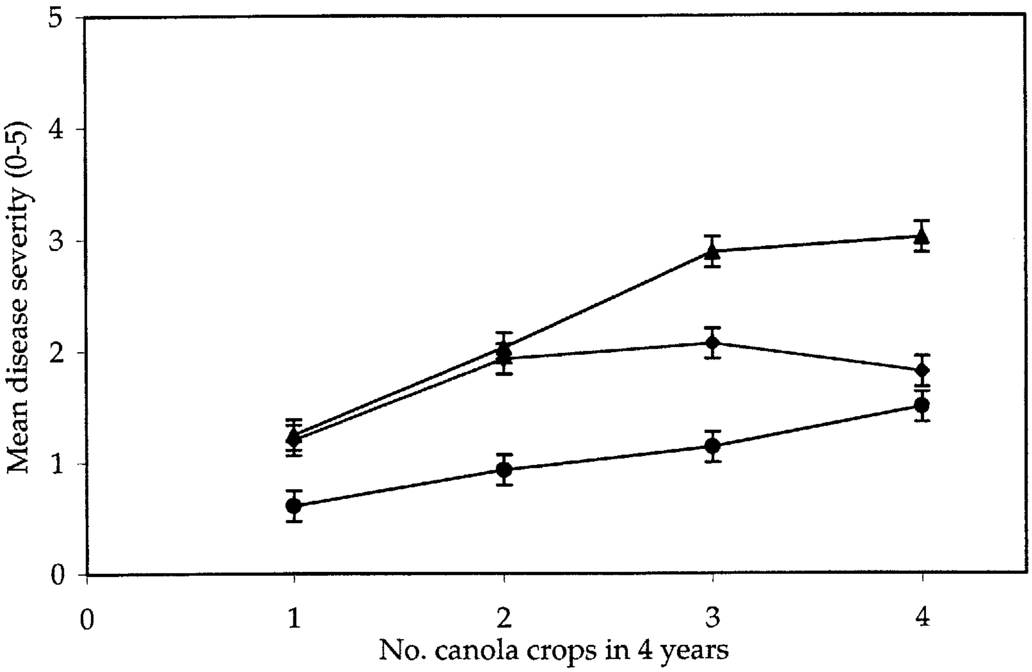


Figure 1. Layout of test plots at Viking, AB, 1995-1999. Numbers at the top of each plot indicate the rotation treatment, where 1=one canola crop in four years, 2=two canola crops in four years, 3=three canola crops in four years, and 4=continuous canola. All plots seeded with Reward canola were also fitted with soil moisture sensors and thermocouples to measure soil water temperature and soil temperature, respectively.



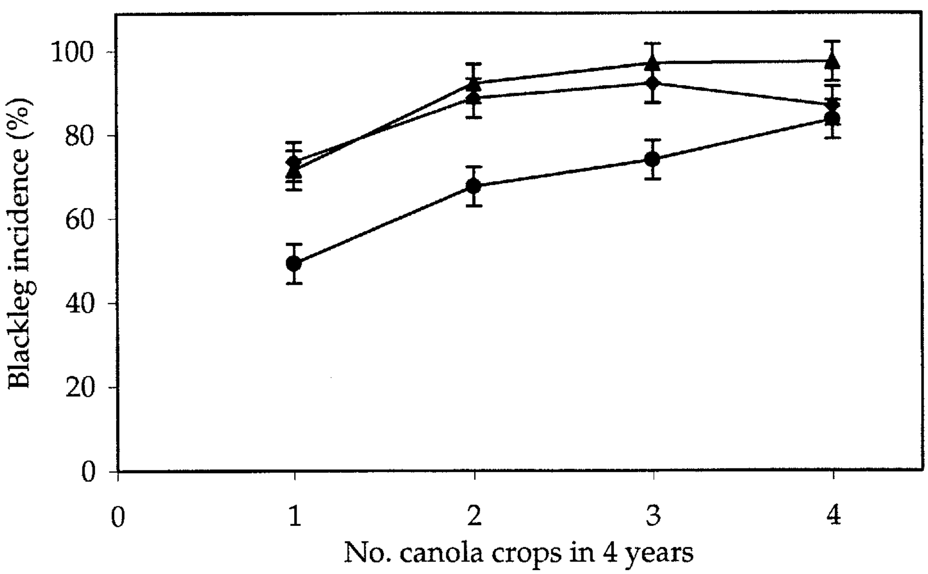


Figure 2. Response of Blackleg disease severity (top) and incidence (bottom) to increasing frequency of canola crops over four growing seasons. Each point is the least-square mean of eight plots. Disease severity was measured using the 0 (no disease) to 5 (dead plant) WCC/RRC scale. Disease incidence was calculated as the percentage of plants in severity classes 1 through 5. Vertical bars indicate the standard error of the least-square mean. *B. napus* cvs. Westar (—▲—), Quantum (—●—) *B. rapa* cv. Reward (—◆—) were included in the experiment.

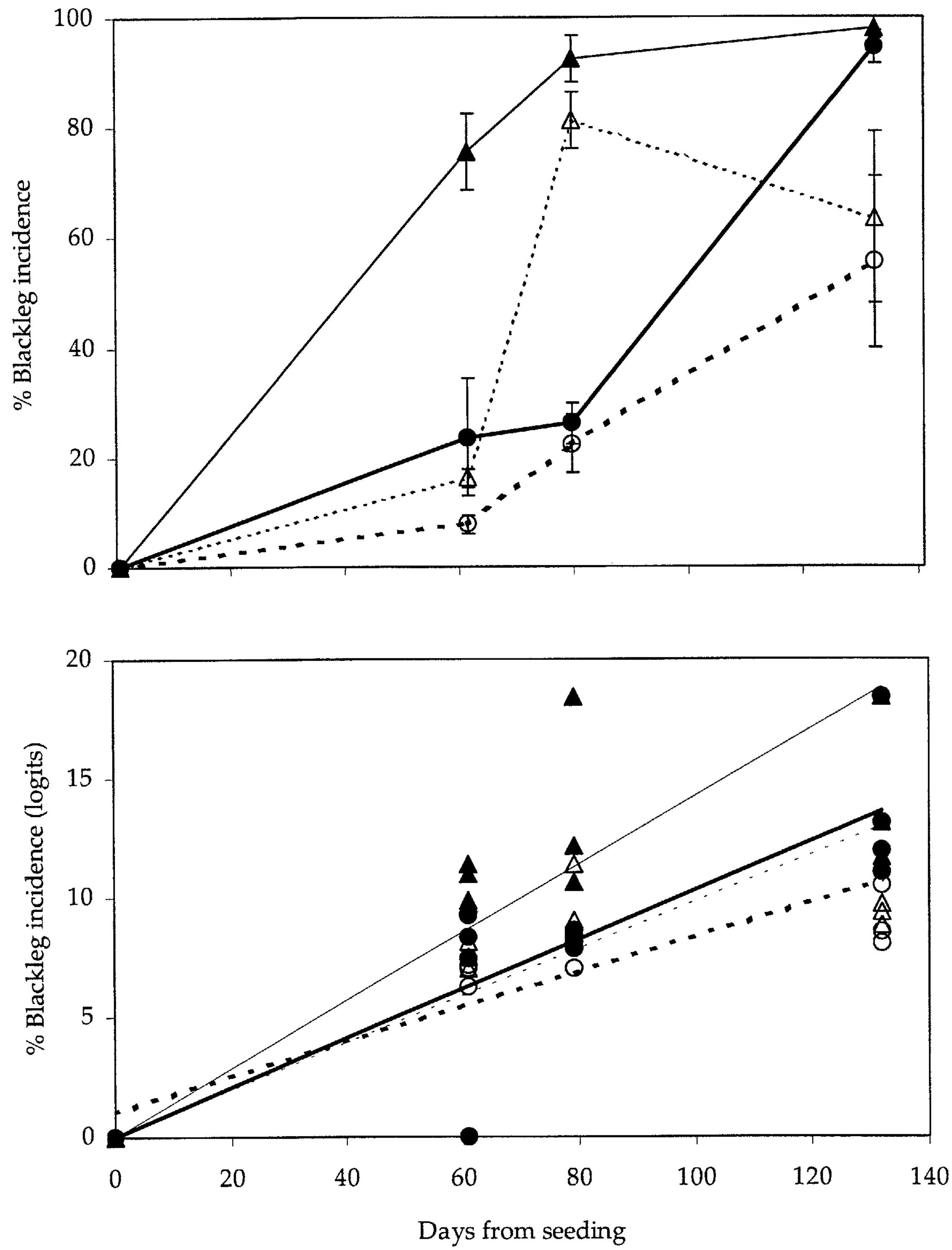


Figure 3. Progress of Blackleg disease incidence in Westar and Quantum canola plots under conventional tillage at Viking AB in 1999. Crops were either grown continuously over the previous four years or under a one canola crop in four year rotation scheme. Raw data (top) were fitted to the logistic disease progress equation (bottom) using zero-intercept linear regressions ($y=rt$) where r is the proportional rate of infection at t days from seeding:

—▲— Westar, continuous, r=0.1424, R^2=0.9488;

- -△- - Westar, 1 in 4, r=0.0934, R^2=0.9104

—●— Quantum, continuous, r=0.1029, R^2=0.9577;

- - O- - Quantum, 1 in 4, r=0.0835, R^2=0.9210.

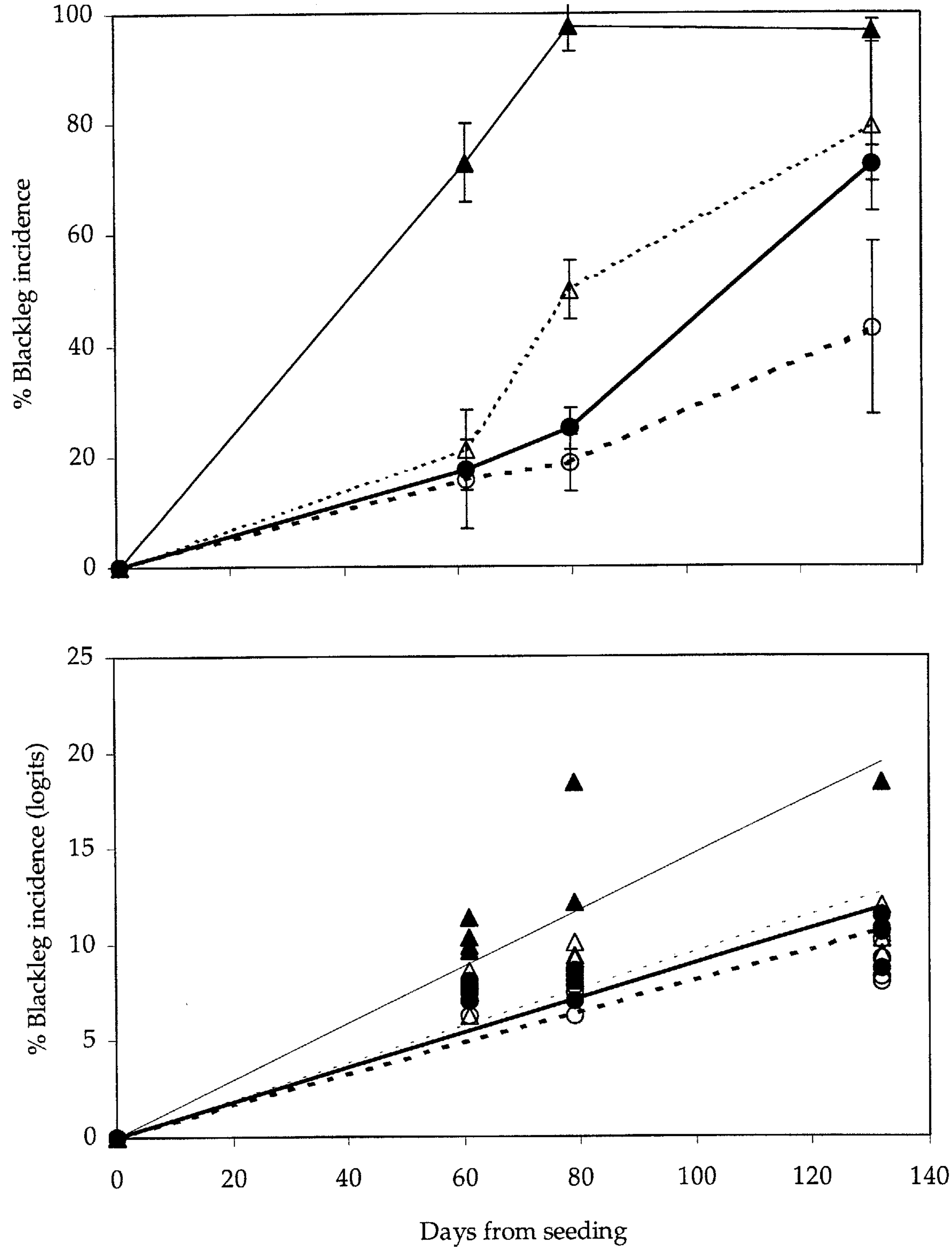


Figure 4. Progress of Blackleg disease incidence in Westar and Quantum canola plots under reduced tillage at Viking AB in 1999. Crops were either grown continuously over the previous four years or under a one canola crop in four year rotation scheme. Raw data (top) were fitted to the logistic disease progress equation (bottom) using zero-intercept linear regressions ($y=rt$) where r is the proportional rate of infection at t days from seeding:

—▲— Westar, continuous, r=0.1470, R^2=0.9314;

- -△- -Westar, 1 in 4, r=0.0963, R^2=0.9565;

—●— Quantum, continuous, r=0.0901, R^2=0.9604

- - O- -Quantum, 1 in 4, r=0.0811, R^2=0.9355.

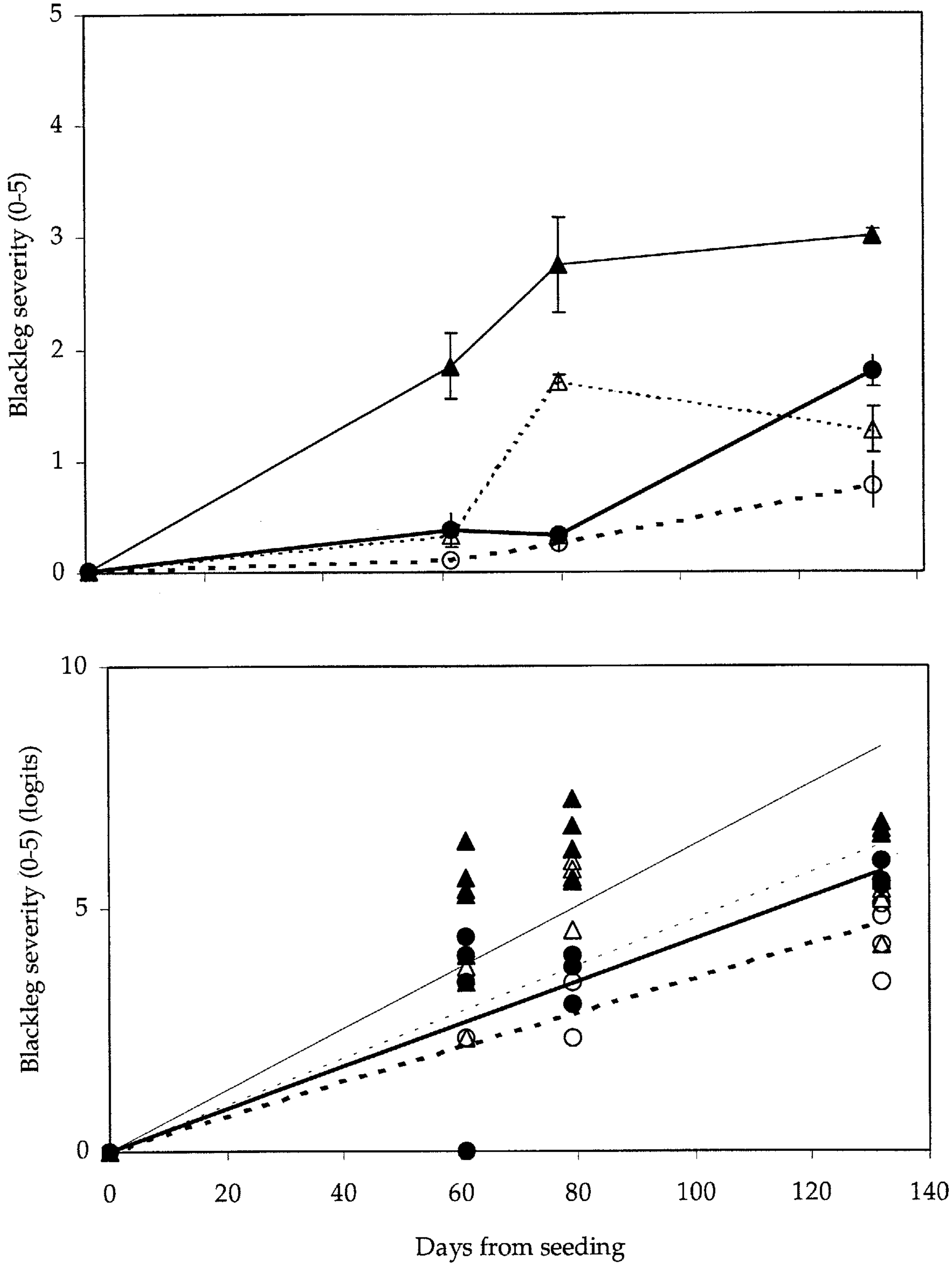


Figure 5. Progress of Blackleg disease severity in Westar and Quantum canola plots under conventional tillage at Viking AB in 1999. Crops were either grown continuously over the previous four years or under a one canola crop in four year rotation scheme. Raw data (top) were fitted to the logistic disease progress equation (bottom) using zero-intercept linear regressions ($y=rt$) where r is the proportional rate of infection at t days from seeding:

—▲— Westar, continuous, r=0.0631, R^2=0. 9245;

- -△- - Westar, 1 in 4, r=0. 0479, R^2=0. 9169;

—●— Quantum, continuous, r=0. 0441, R^2=0. 9408

- -O- - Quantum, 1 in 4, r=0. 0354, R^2=0. 9743.

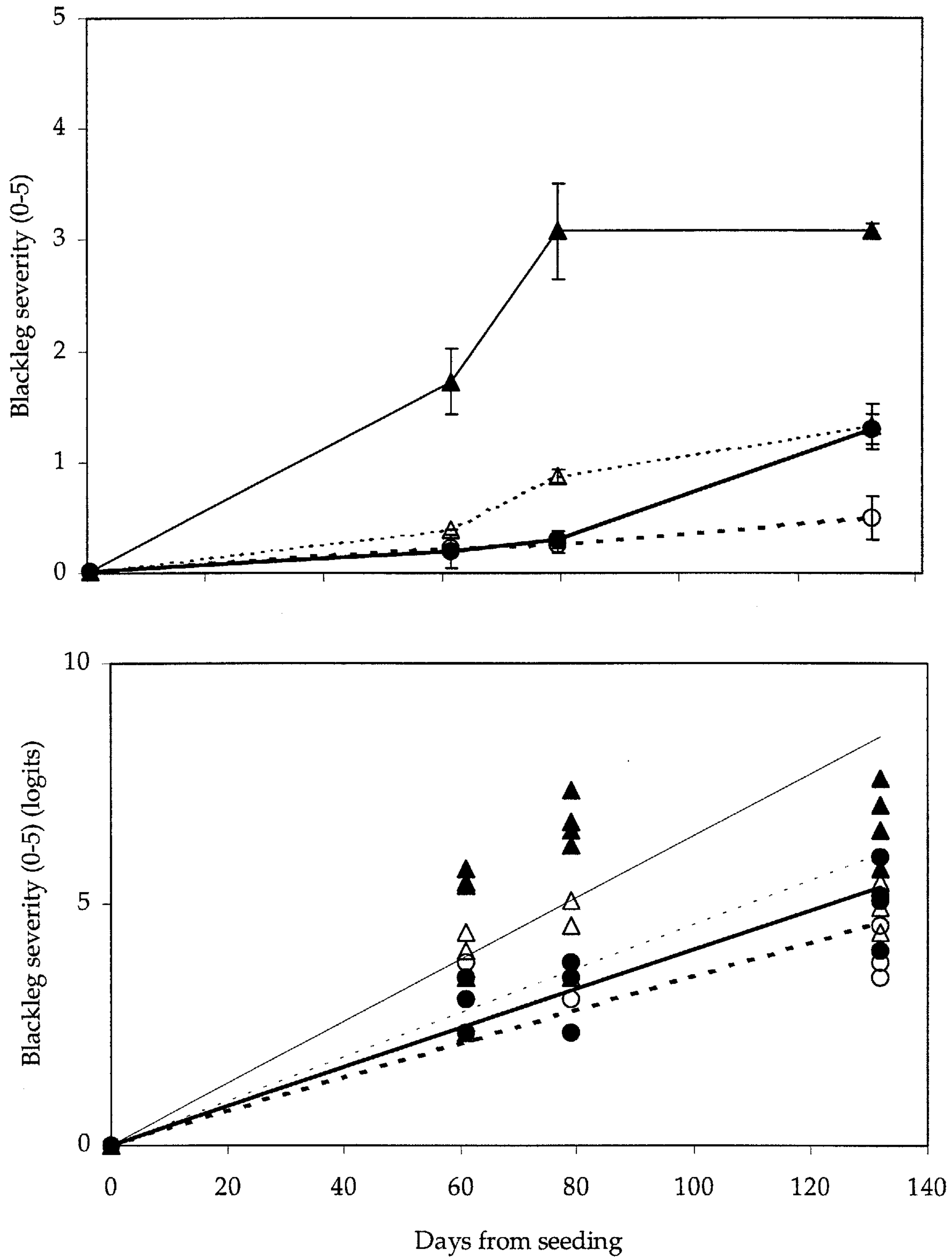


Figure 6. Progress of Blackleg disease severity in Westar and Quantum canola plots under reduced tillage at Viking AB in 1999. Crops were either grown continuously over the previous four years or under a one canola crop in four year rotation scheme. Raw data (top) were fitted to the logistic disease progress equation (bottom) using zero-intercept linear regressions ($y=rt$) where r is the proportional rate of infection at t days from seeding:

—▲— Westar, continuous, r=0.0642, R^2=0. 9252;

- -△- - Westar, 1 in 4, r=0. 0457, R^2=0. 9416;

—●— Quantum, continuous, r=0. 0406, R^2=0. 9709

- -O- - Quantum, 1 in 4, r=0. 0349, R^2=0. 9399.

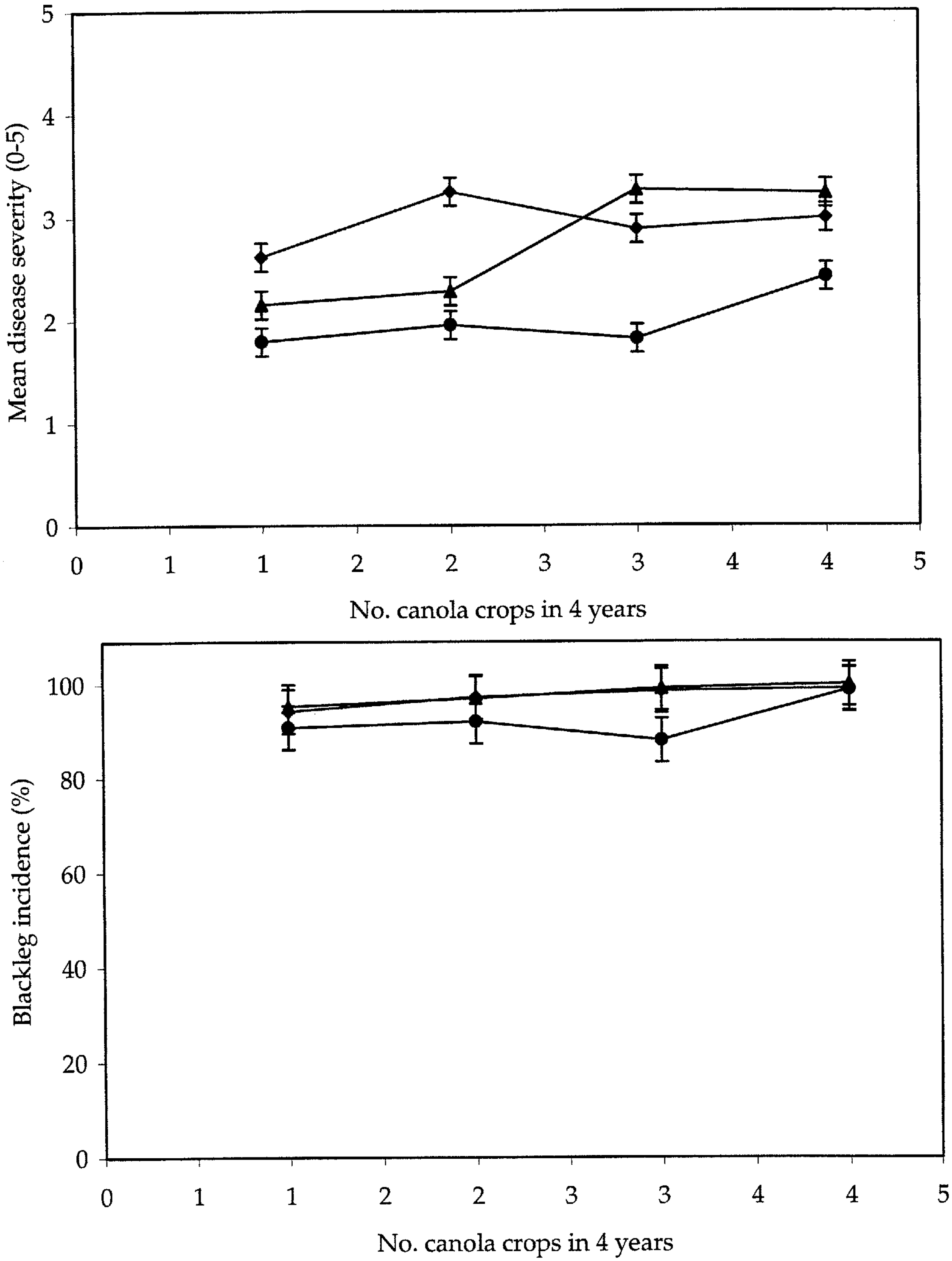


Figure 7. Response of root rot disease severity (top) and incidence (bottom) to increasing frequency of canola crops over four growing seasons. Each point is the least-square mean of eight plots. Disease severity was measured using a 0 (no disease) to 5 (dead plant) severity scale. Disease incidence was calculated as the percentage of plants in severity classes 1 through 5. Vertical bars indicate the standard error of the least-square mean. *B. napus* cvs. Westar (—▲—), Quantum (—●—) and *B. rapa* cv. Reward (—♦—) were included in the experiment.

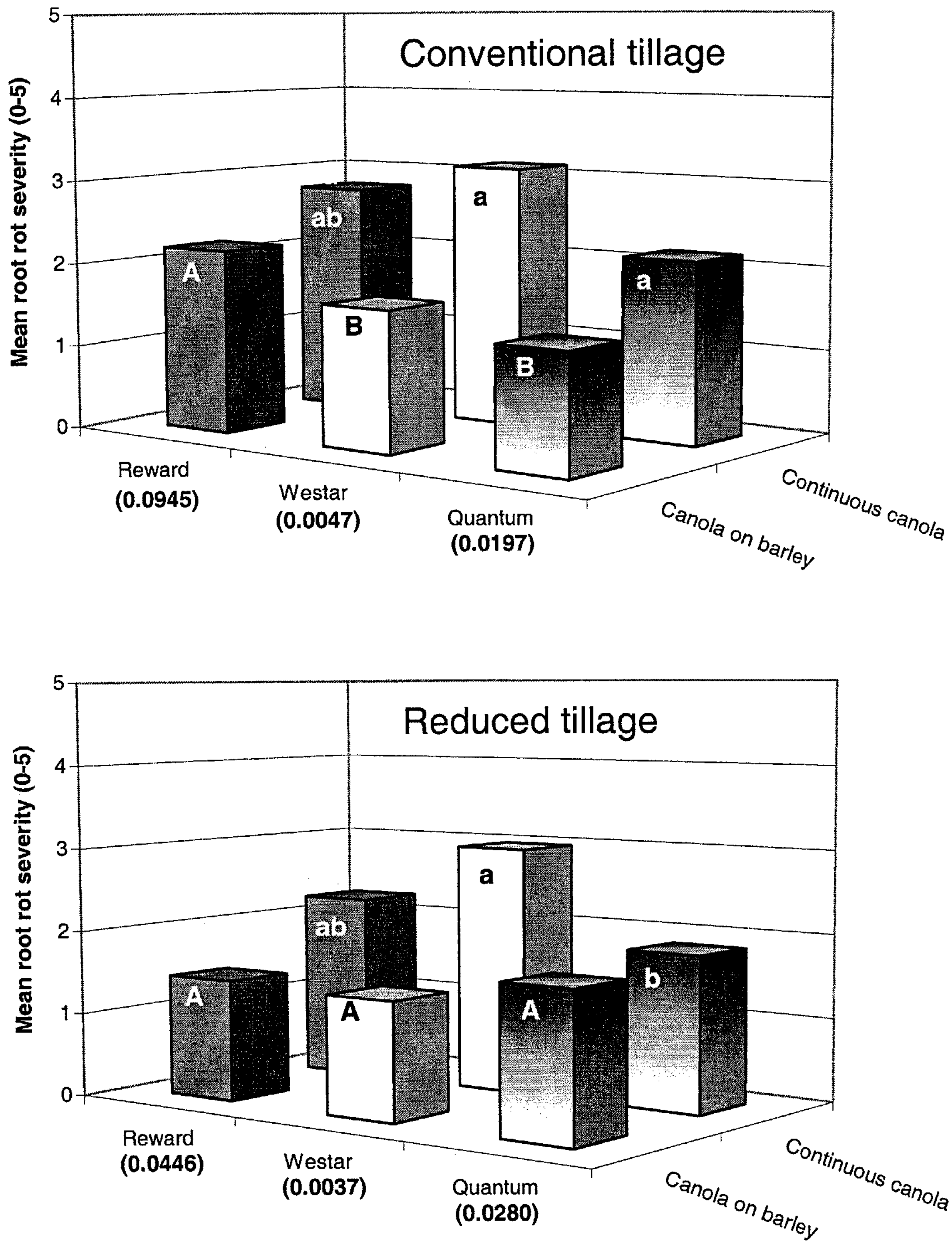


Figure 8. Effect of crop rotation on mean root rot disease severity of three canola cultivars using conventional and reduced tillage at Viking AB in 1997. Columns within a rotation system with the same letter are not significantly different by Duncan's multiple range test α=0.05. Figures in brackets below cultivar names indicate significance level (P>|T|) for comparisons between rotation systems within cultivars. Significant differences are highlighted with boldface type.

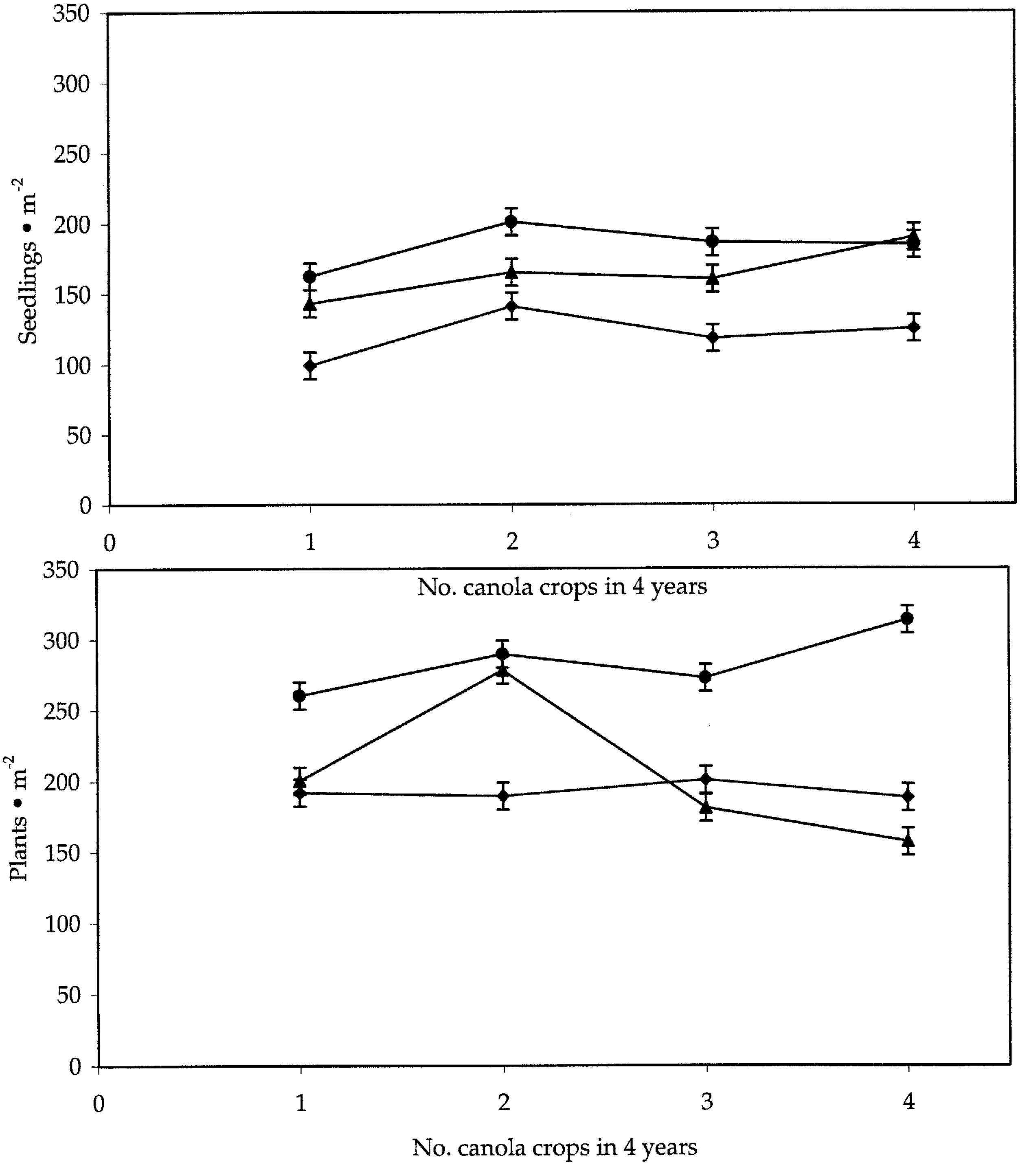


Figure 9. Response of seedling emergence (top) and plant stand at harvest (bottom) to increasing frequency of canola crops over four growing seasons. Each point is the least-square mean of eight plots. Vertical bars indicate the standard error of the least-square mean. *B. napus* cvs. Westar (—▲—), Quantum (—●—) and *B. rapa* cv. Reward (—◆—) were included in the experiment.

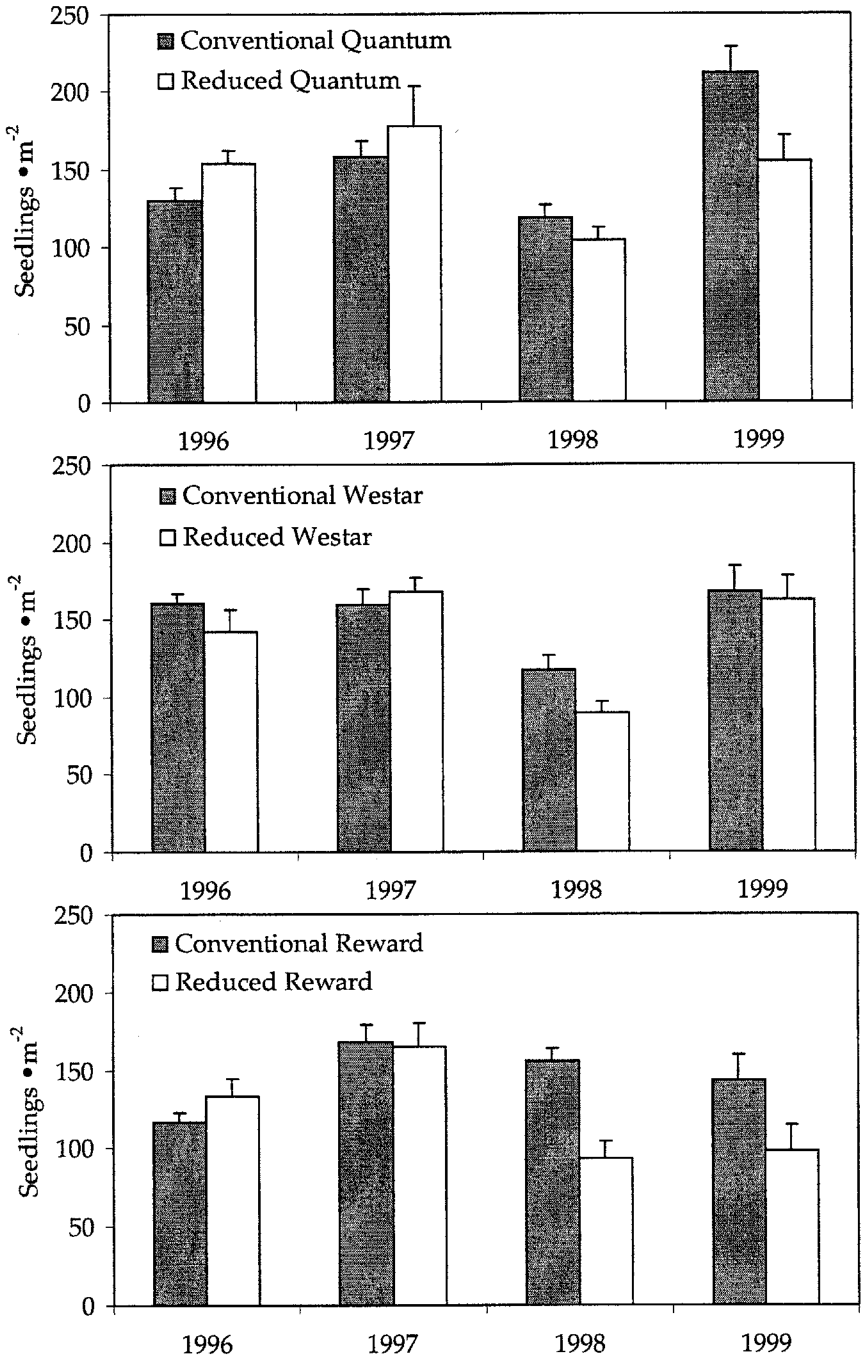


Figure 10. Response of Quantum, Westar and Reward seedling emergence to conventional and reduced tillage at Viking, AB, 1996-1999. Vertical bars indicate standard error of the mean.

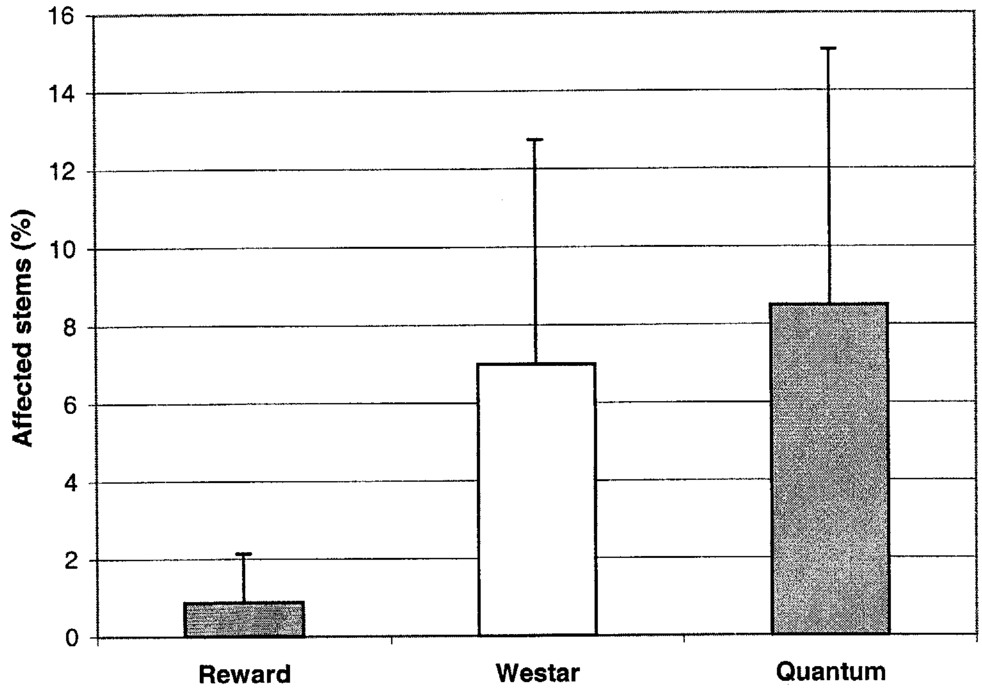


Figure 11. Incidence of Sclerotinia stem rot on three canola cultivars at Viking AB in 1997. Vertical bars indicate standard deviation.

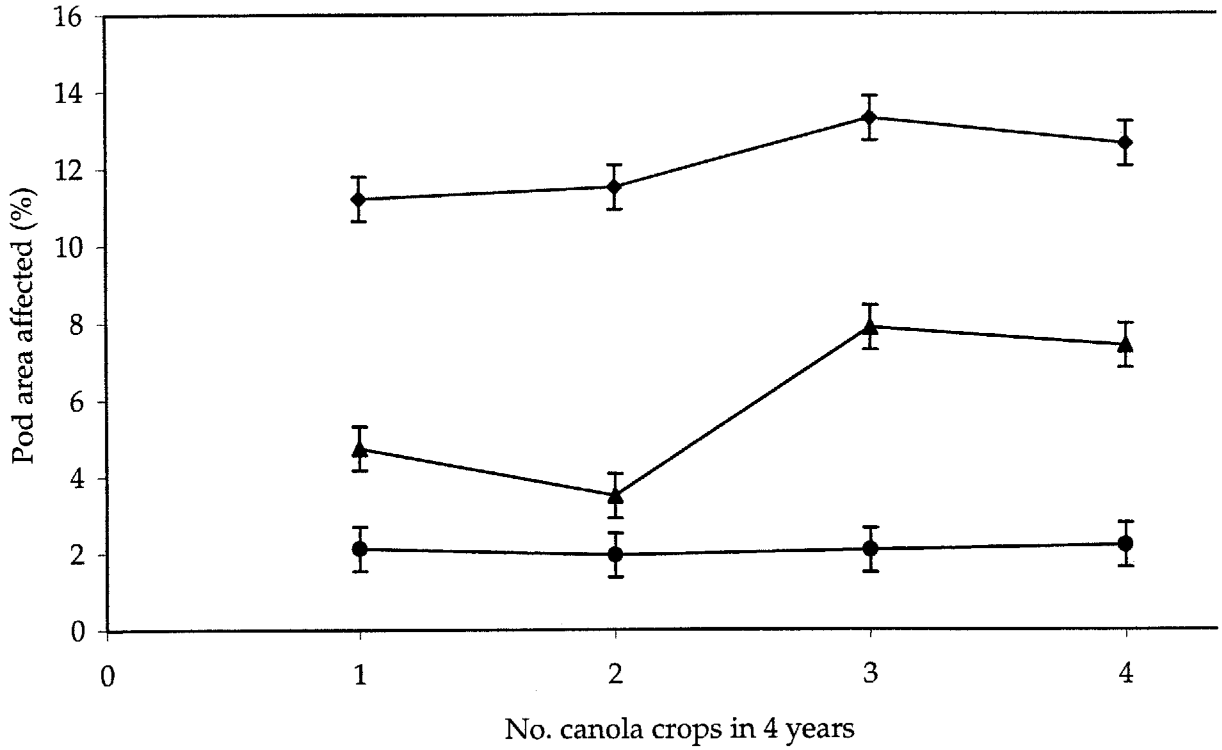


Figure 12. Response of Alternaria black spot severity to increasing frequency of canola crops over four growing seasons. Each point is the least-square mean of eight plots. Vertical bars indicate the standard error of the least-square mean. *B. napus* cvs. Westar (—▲—), Quantum (—●—) and *B. rapa* cv. Reward (—♦—) were included in the experiment.

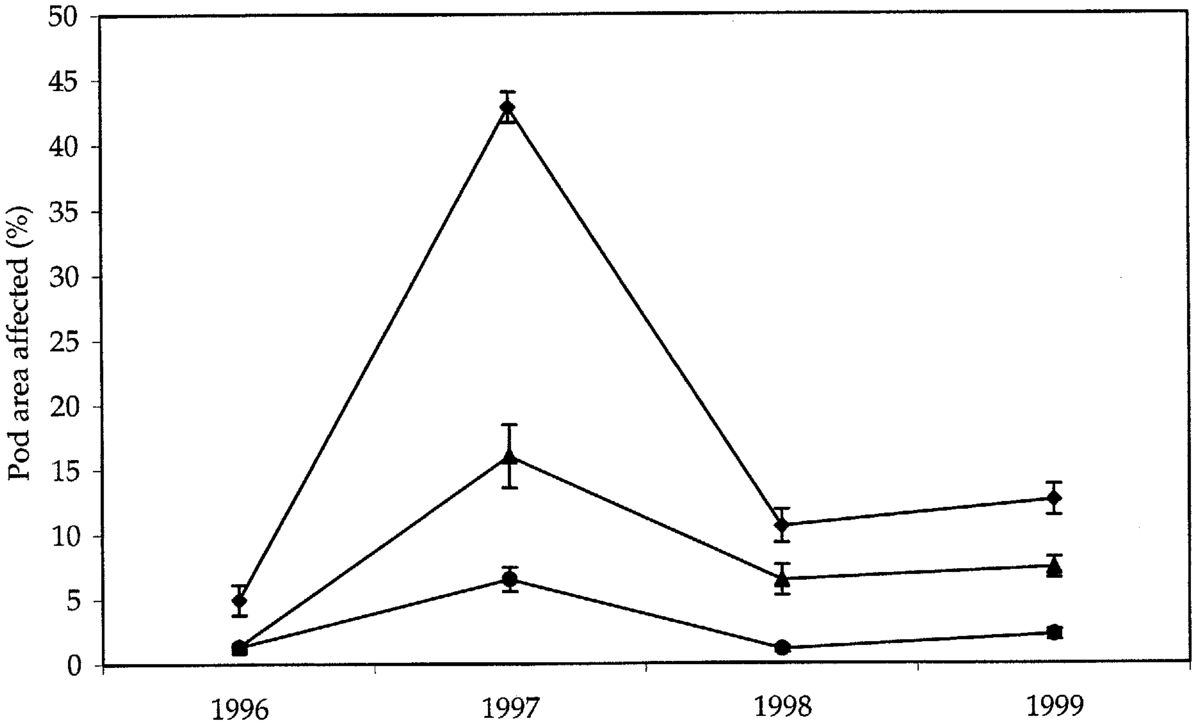


Figure 13. Severity of Alternaria black spot in three canola cultivars at Viking, Alberta, 1996-1997. Each point indicates the mean severity in continuous canola plots. Vertical bars indicate the standard error of the mean. *B. napus* cvs. Westar (—▲—), Quantum (—●—) and *B. rapa* cv. Reward (—◆—) were included in the experiment.

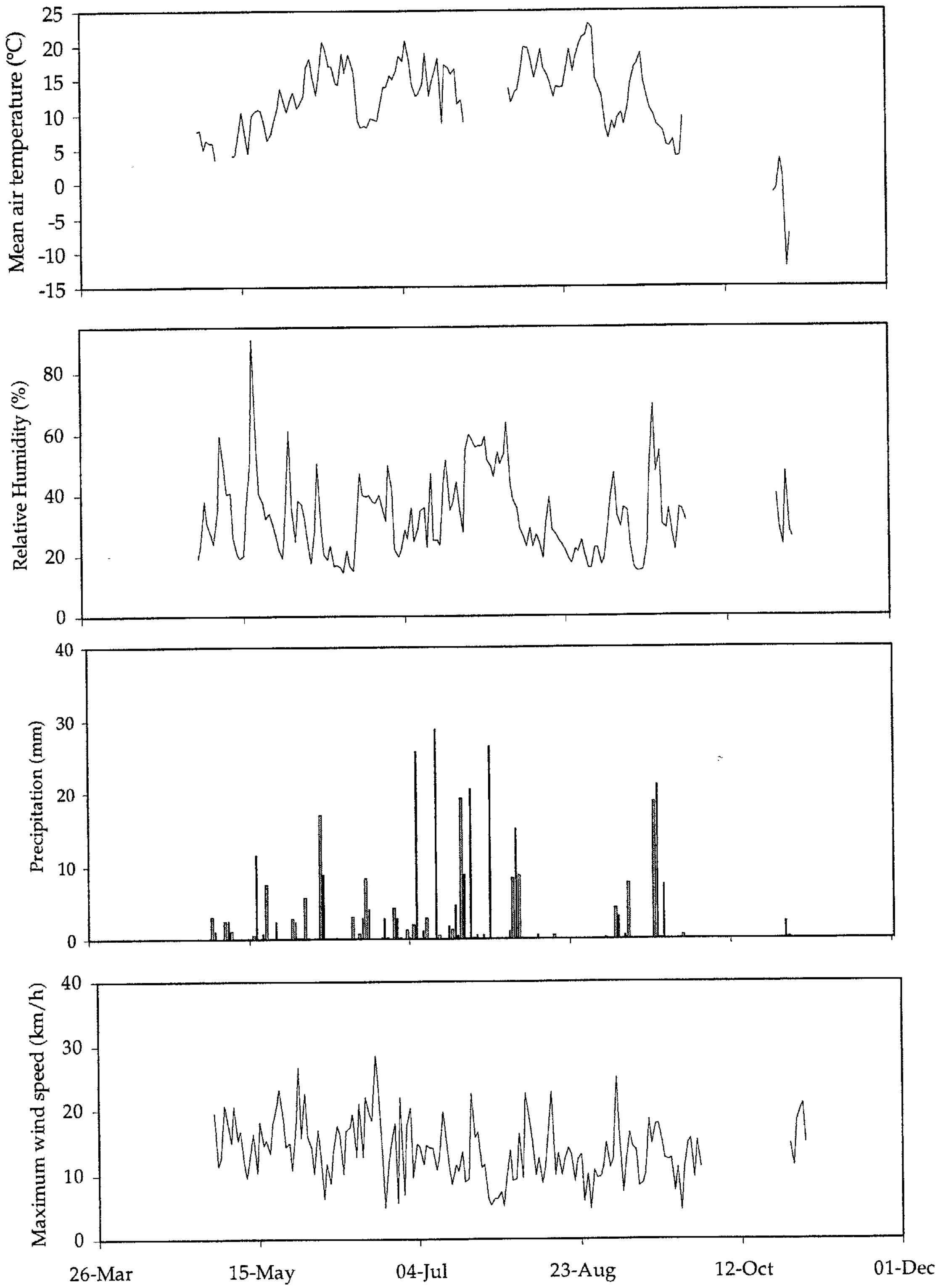


Figure 14. Average daily air temperature, relative humidity, rainfall and wind speed at Viking in 1996.

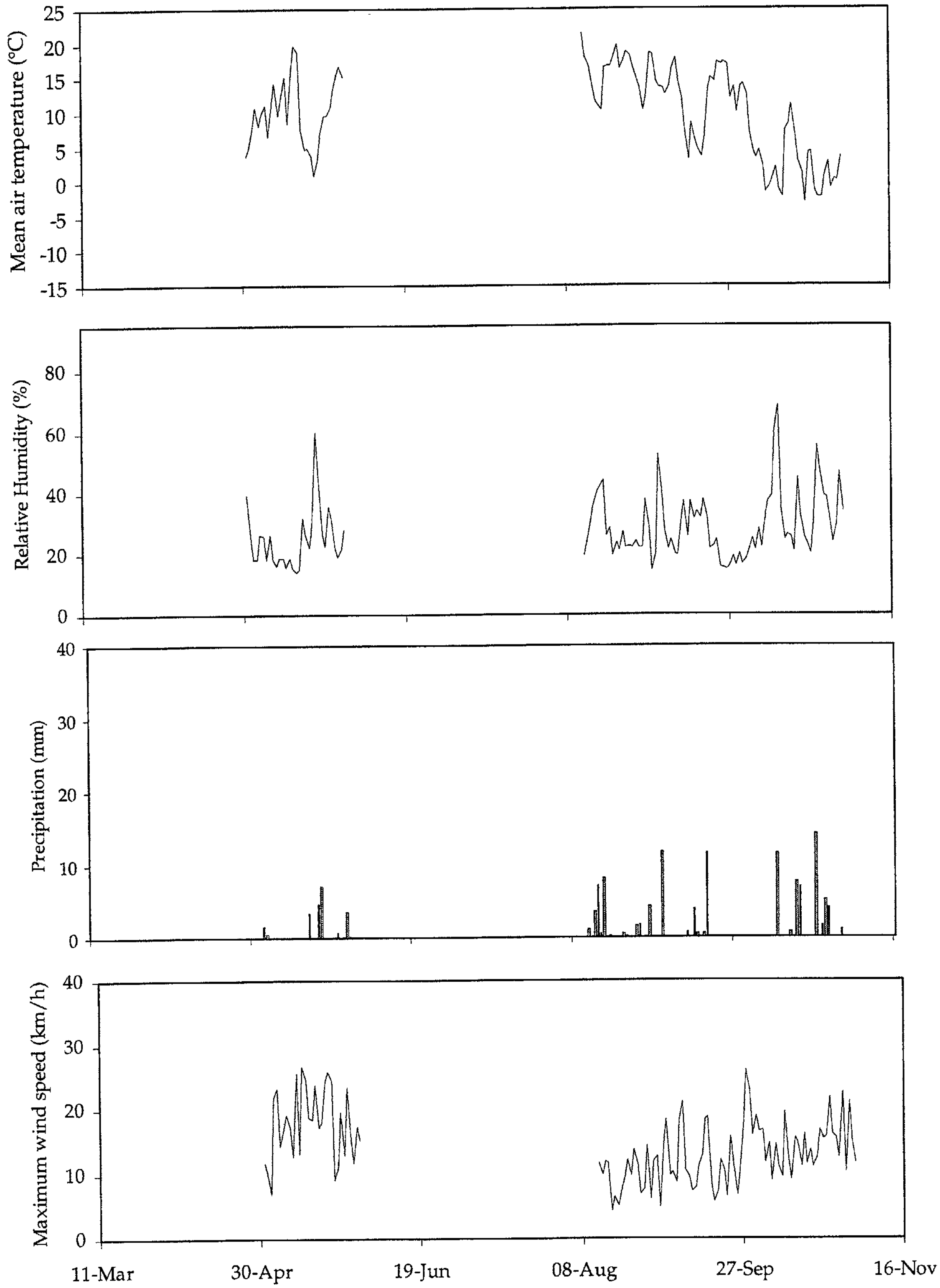


Figure 15. Average daily air temperature, relative humidity, rainfall and wind speed at Viking in 1997.

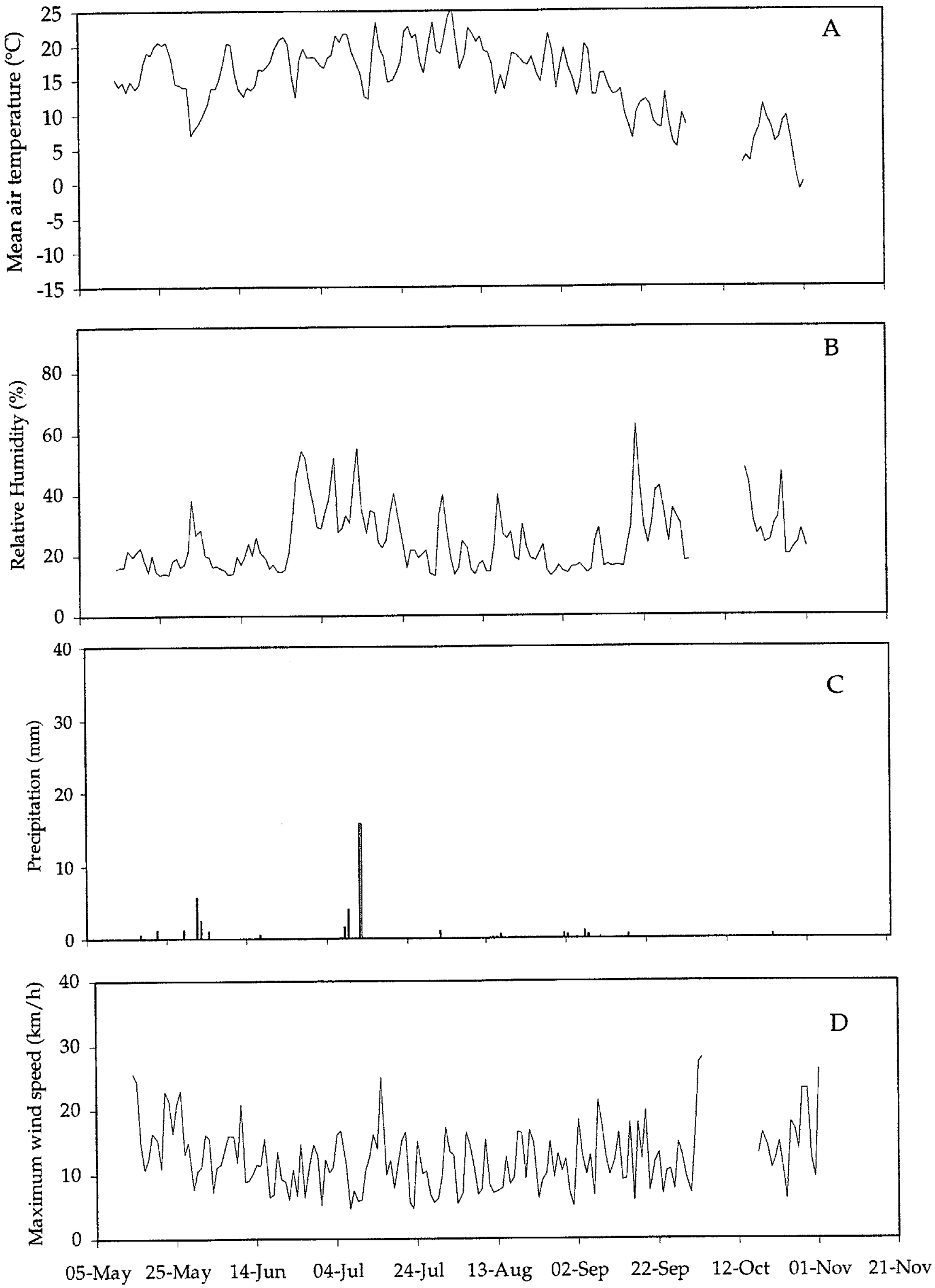


Figure 16. Average daily air temperature, relative humidity, rainfall and wind speed at Viking in 1998.

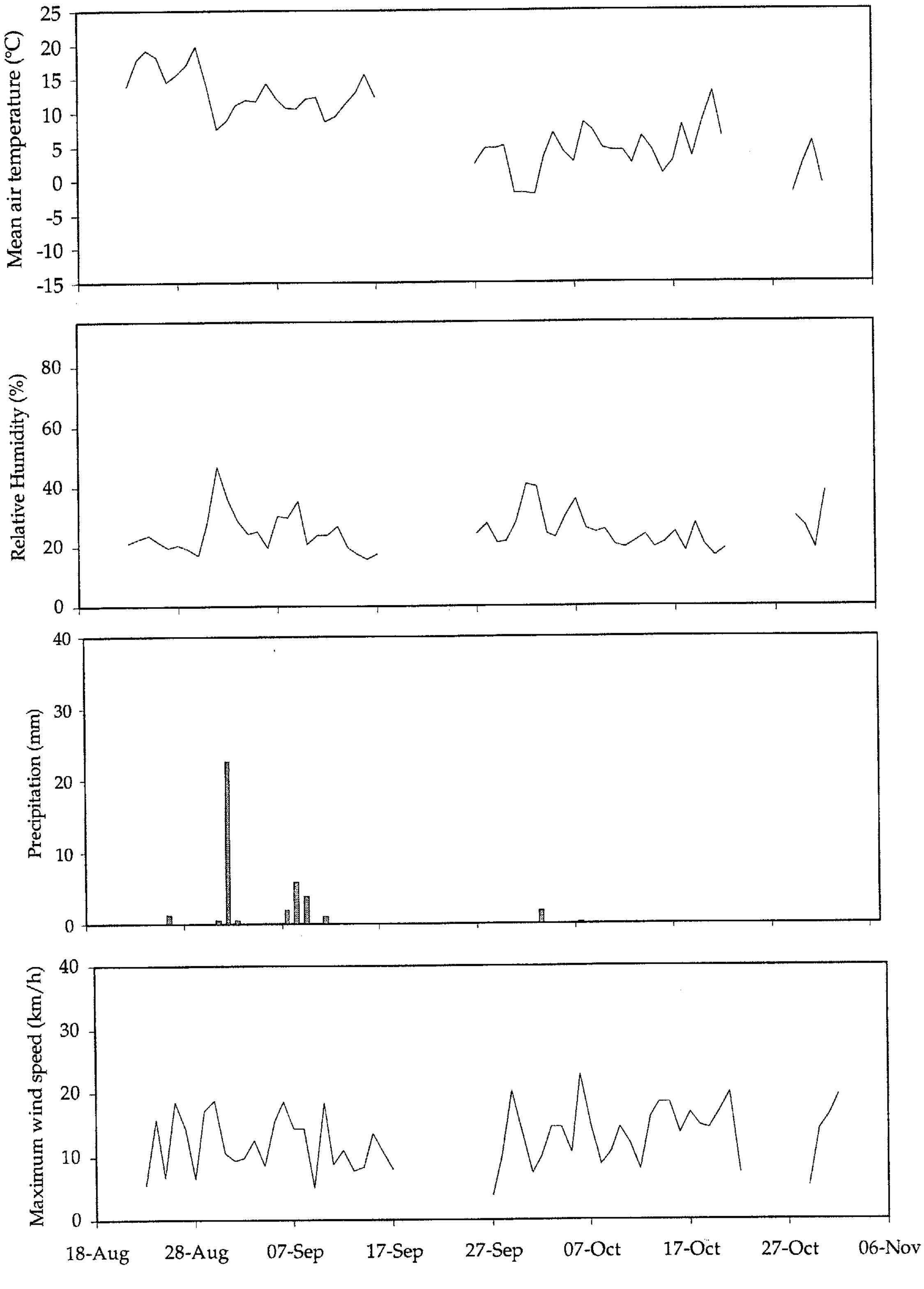


Figure 17. Average daily air temperature, relative humidity, rainfall and wind speed at Viking in 1999.

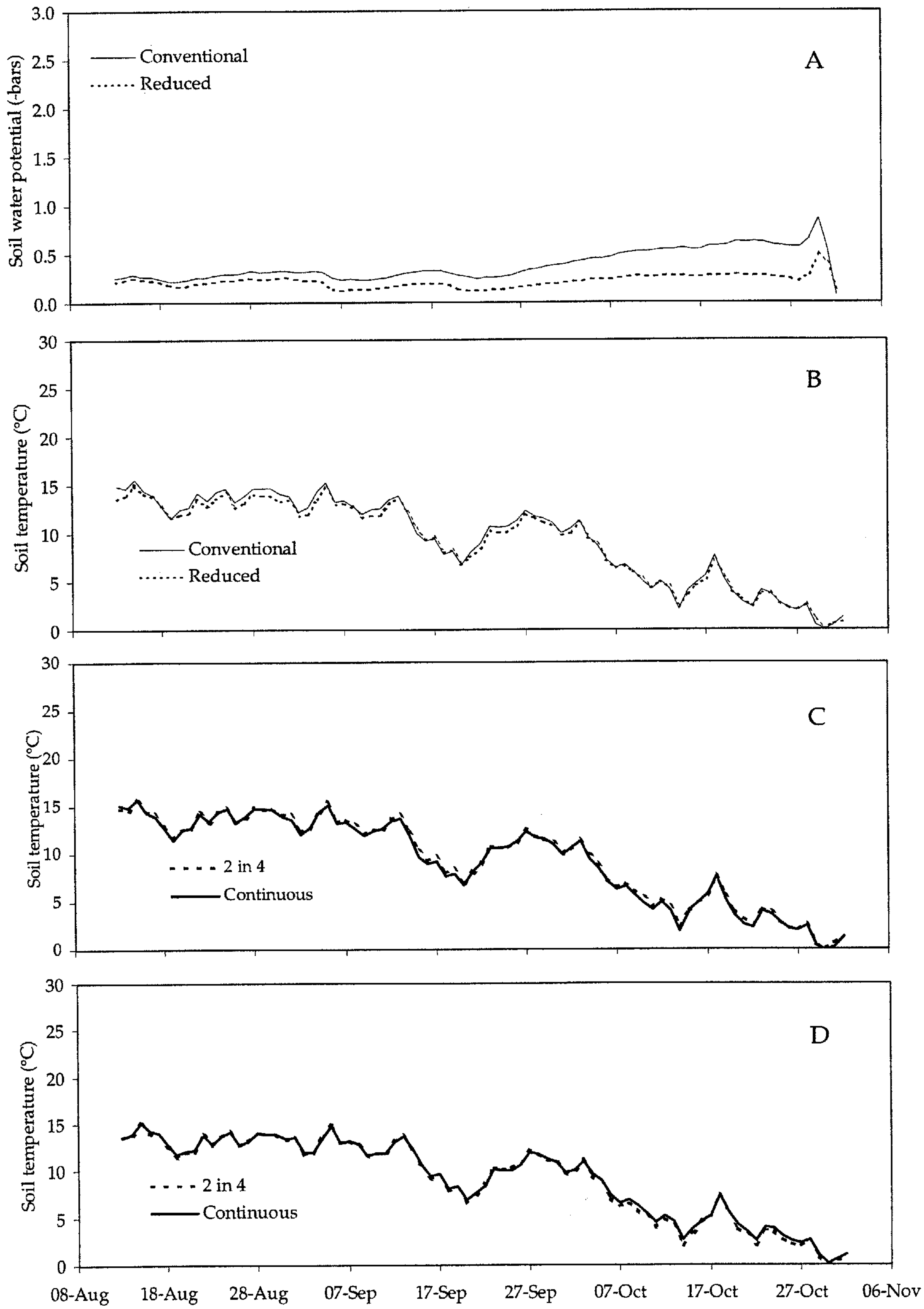


Figure 18. Average daily soil water potential (A) and temperature (B) 15 cm below the soil surface under two tillage systems at Viking AB in 1997. The bottom two figures compare average daily soil temperature in the 2 canola crop in four year and continuous canola rotation treatments under conventional (C) and reduced tillage (D).

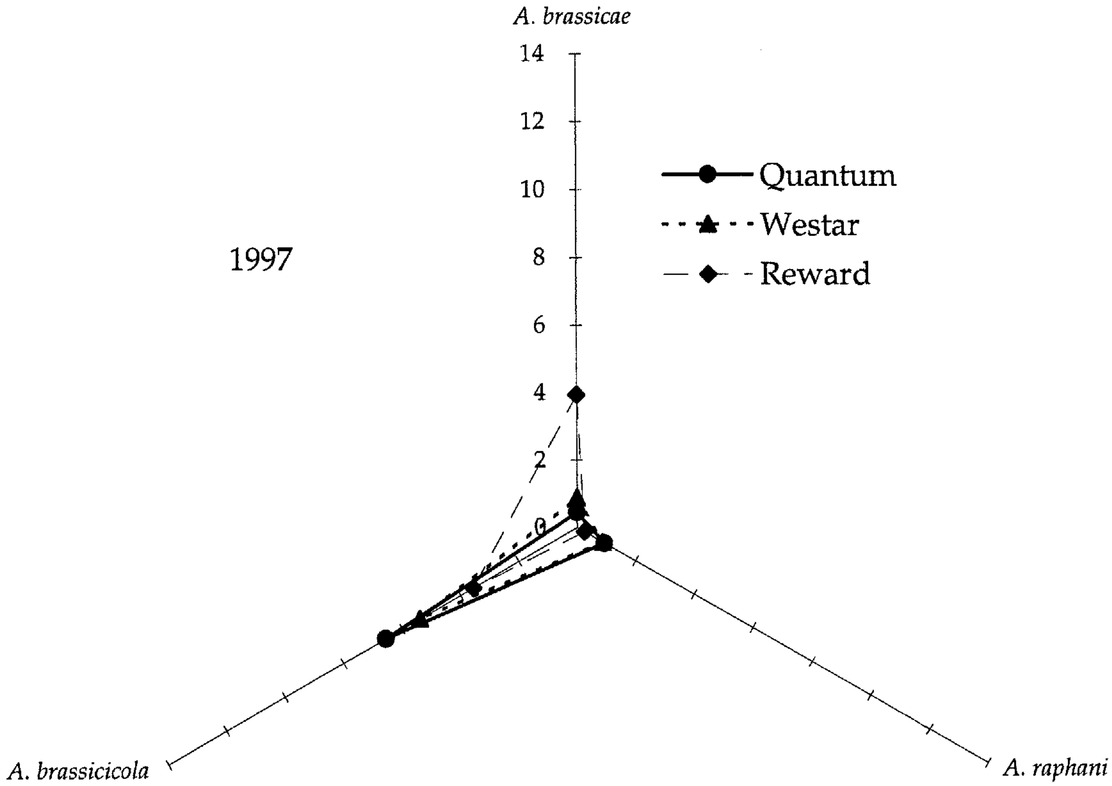


Figure 19. Incidence of seed-borne *Alternaria brassicae, A. raphani* and *A. brassicicola* in two *Brassica napus* canola cultivars (Quantum and Westar) and on *B. rapa* cultivar cv. Reward at Viking in 1997. Each axis indicates the percentage of seeds from which each fungus was isolated following surface sterilization and incubation on V-8 juice agar. Each point is the mean of 800 seeds. Standard error of the least-square mean was 0.7 and 0.6 for *A. brassicae* and *A. brassicicola*, respectively, in all cultivars. For *A. raphani*, the standard error was 0.9 in Quantum and Westar, and 0.3 in Reward.

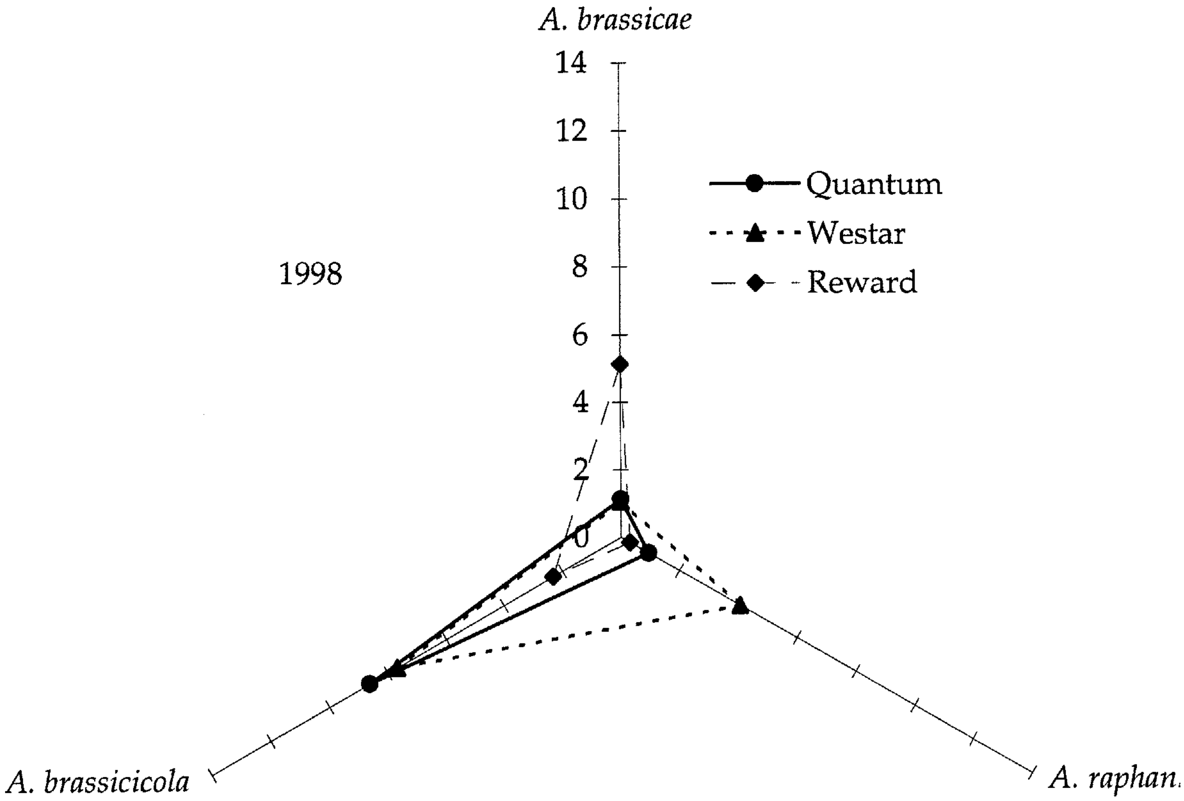


Figure 20. Incidence of seed-borne *Alternaria brassicae, A. raphani* and *A. brassicicola* in two *Brassica napus* canola cultivars (Quantum and Westar) and on *B. rapa* cultivar (Reward) at Viking in 1998. Each axis indicates the percentage of seeds from which each fungus was isolated following surface sterilization and incubation on V-8 juice agar. Each point is the mean of 800 seeds. Standard error of the least-square mean was 0.5, 0.5 and 1.1 for *A. brassicae, A. raphani* and *A. brassicicola,* respectively, in all cultivars.

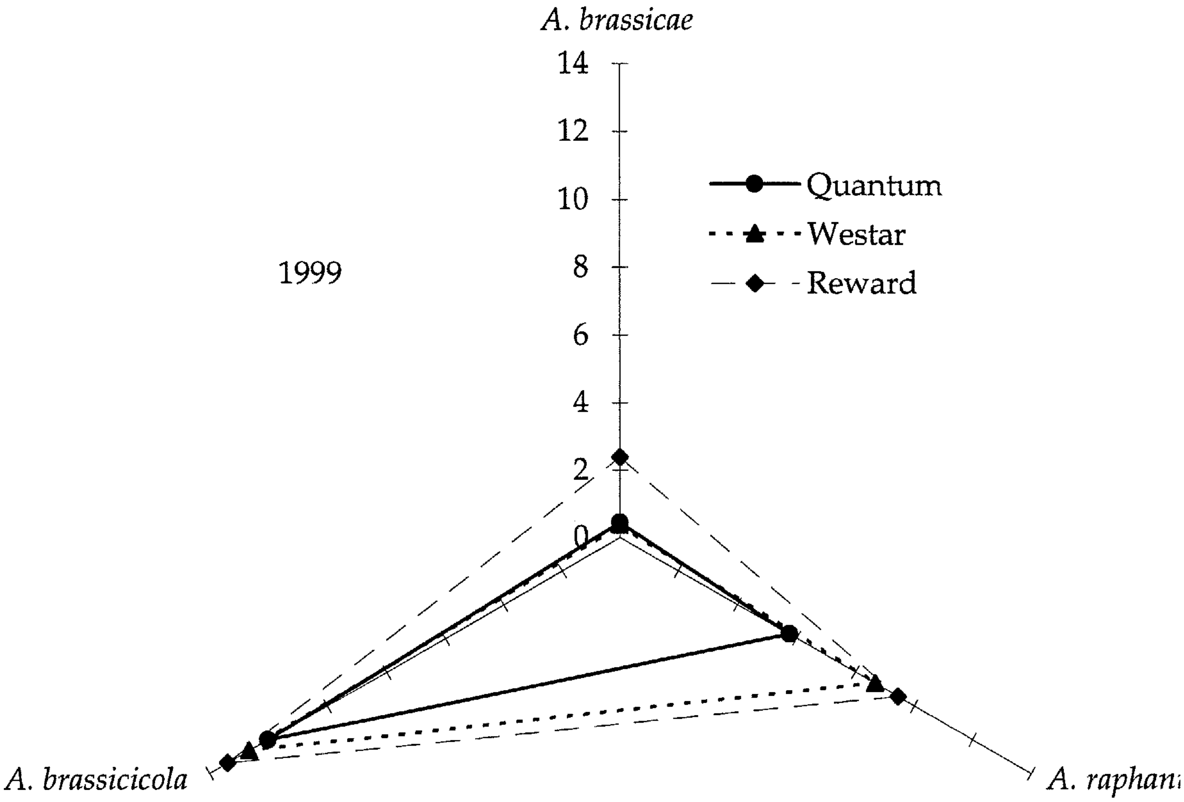


Figure 21. Incidence of seed-borne *Alternaria brassicae, A. raphani* and *A. brassicicola* in two *Brassica napus* canola cultivars (Quantum and Westar) and on *B. rapa* cultivar (Reward) at Viking in 1999. Each axis indicates the percentage of seeds from which each fungus was isolated following surface sterilization and incubation on V-8 juice agar. Each point is the mean of 400 seeds. Standard error of the least-square mean was 0.5, 1.1 and 1.3 for *A. brassicae, A. raphani* and *A. brassicicola,* respectively, in all cultivars.

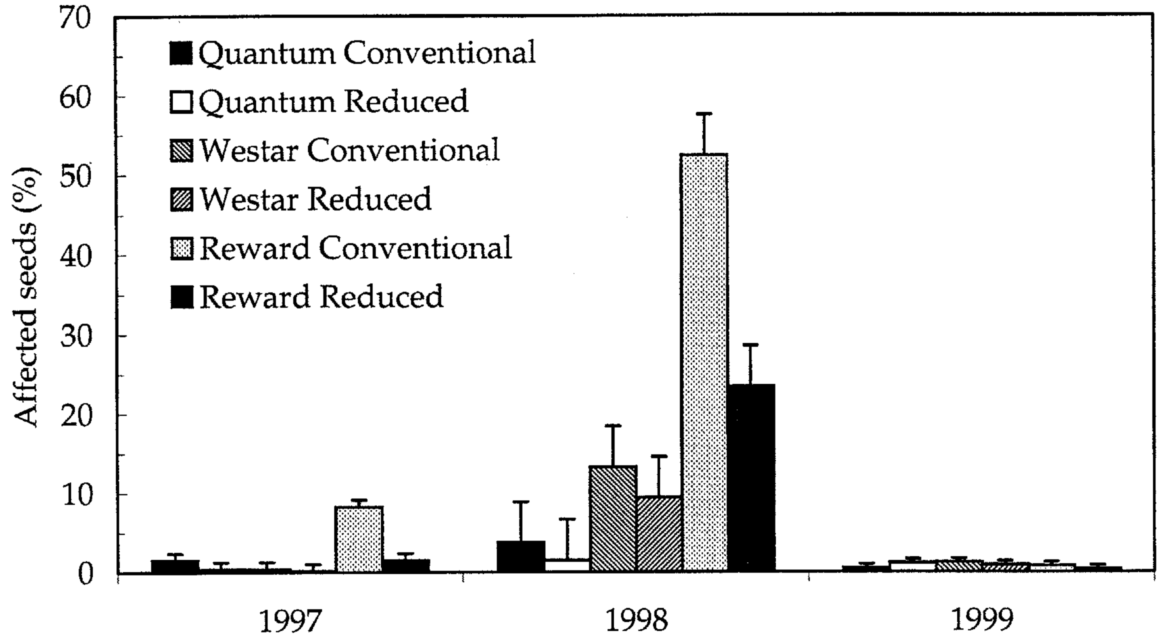


Figure 22. Effect of tillage method on seed infection by *Leptosphaeria maculans* at Viking, AB, 1997-1999. Vertical lines indicate standard error of the mean. Each column represents the least-square mean percentage of 800 (1997 and 1998) or 400 (1999) surface-sterilized seeds colonized by *L. maculans*.

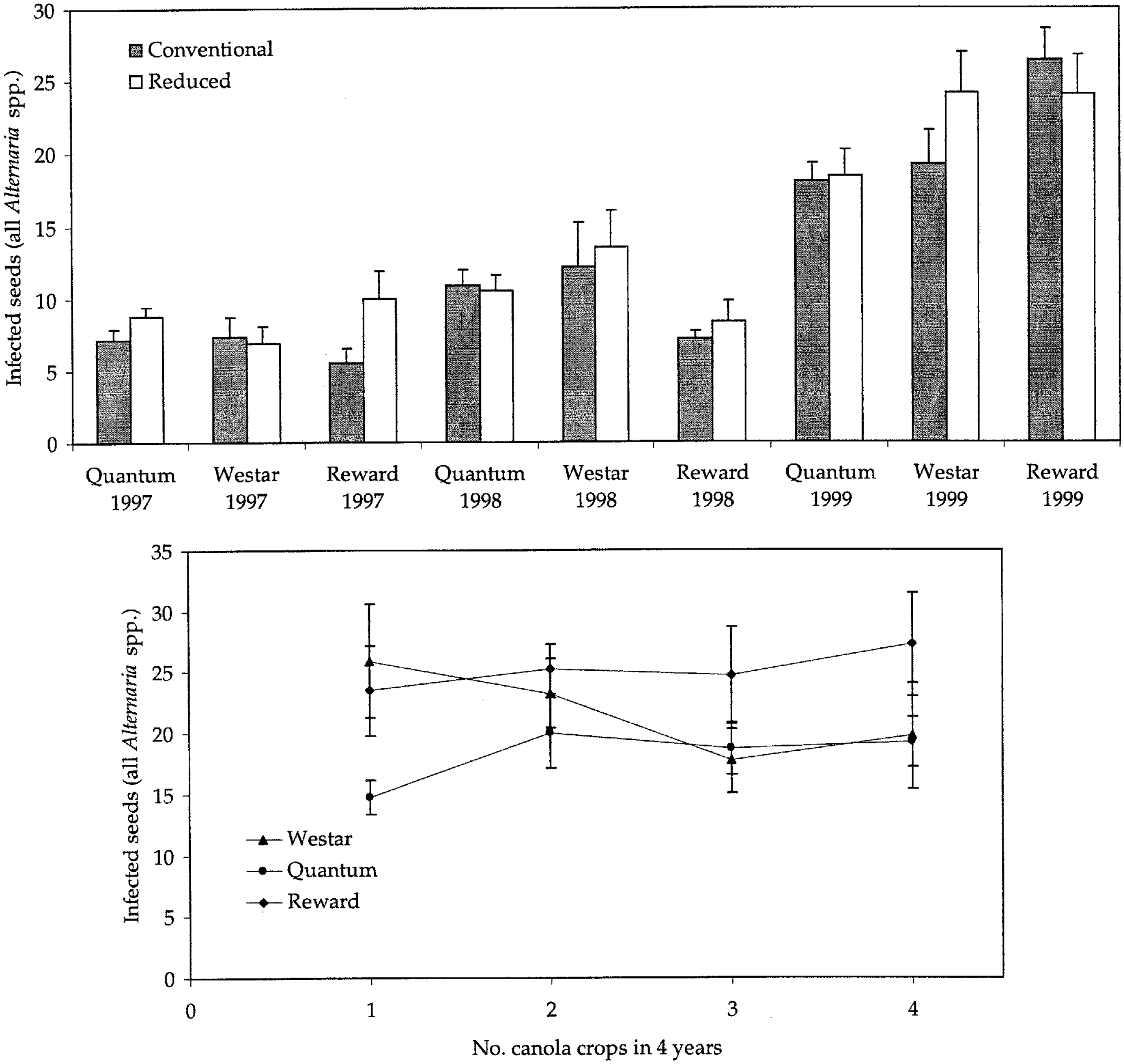


Figure 23. Response of *Alternaria* spp. seed transmission to tillage method (top) and crop rotation (bottom). Vertical axes indicate the total percentage of seeds infected with *Alternaria brassicae, A. raphani* or *A. brassicicola*. Vertical bars indicate standard error of the mean.

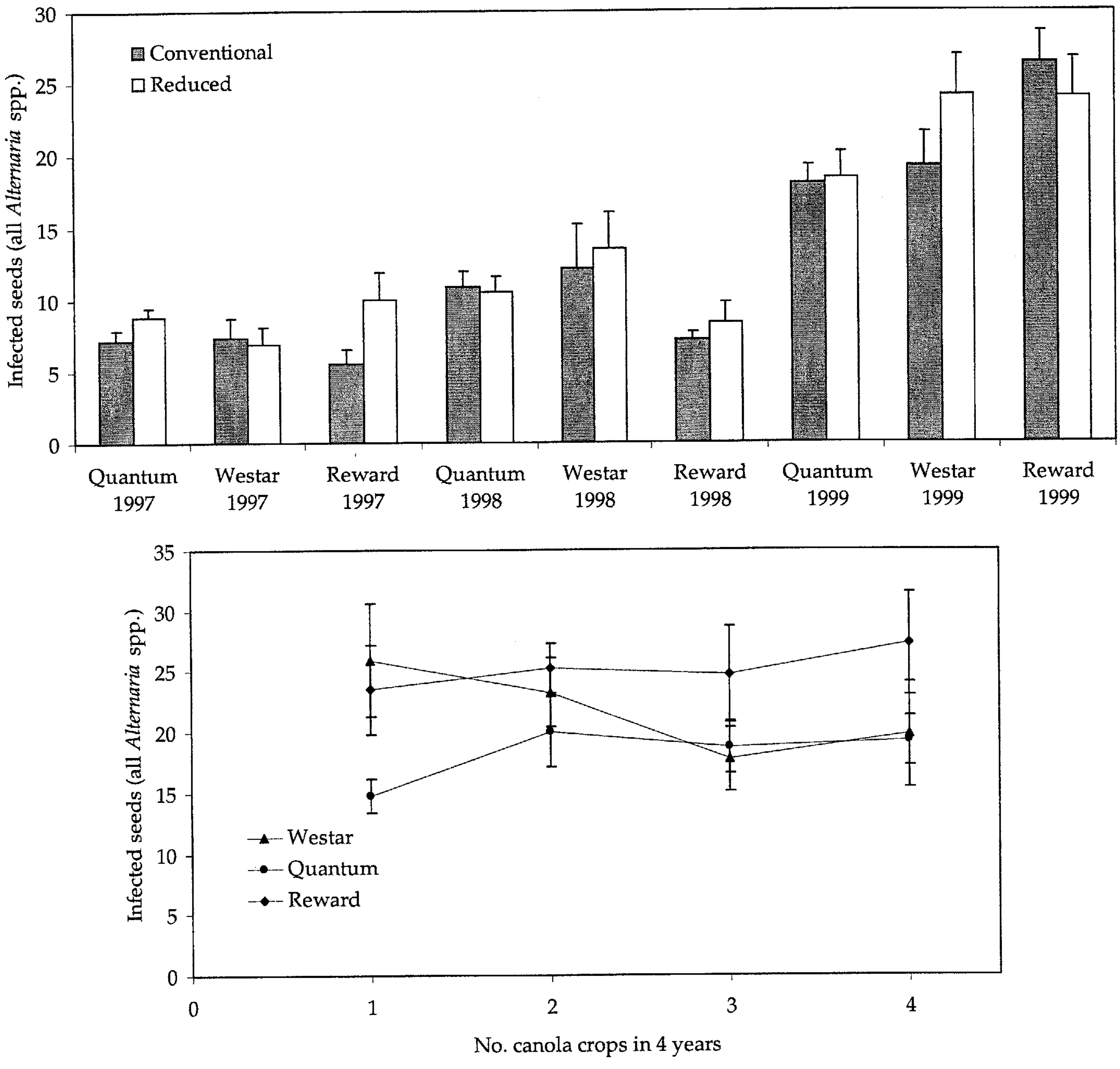


Figure 23. Response of *Alternaria* spp. seed transmission to tillage method (top) and crop rotation (bottom). Vertical axes indicate the total percentage of seeds infected with *Alternaria brassicae, A. raphani* or *A. brassicicola*. Vertical bars indicate standard error of the mean.

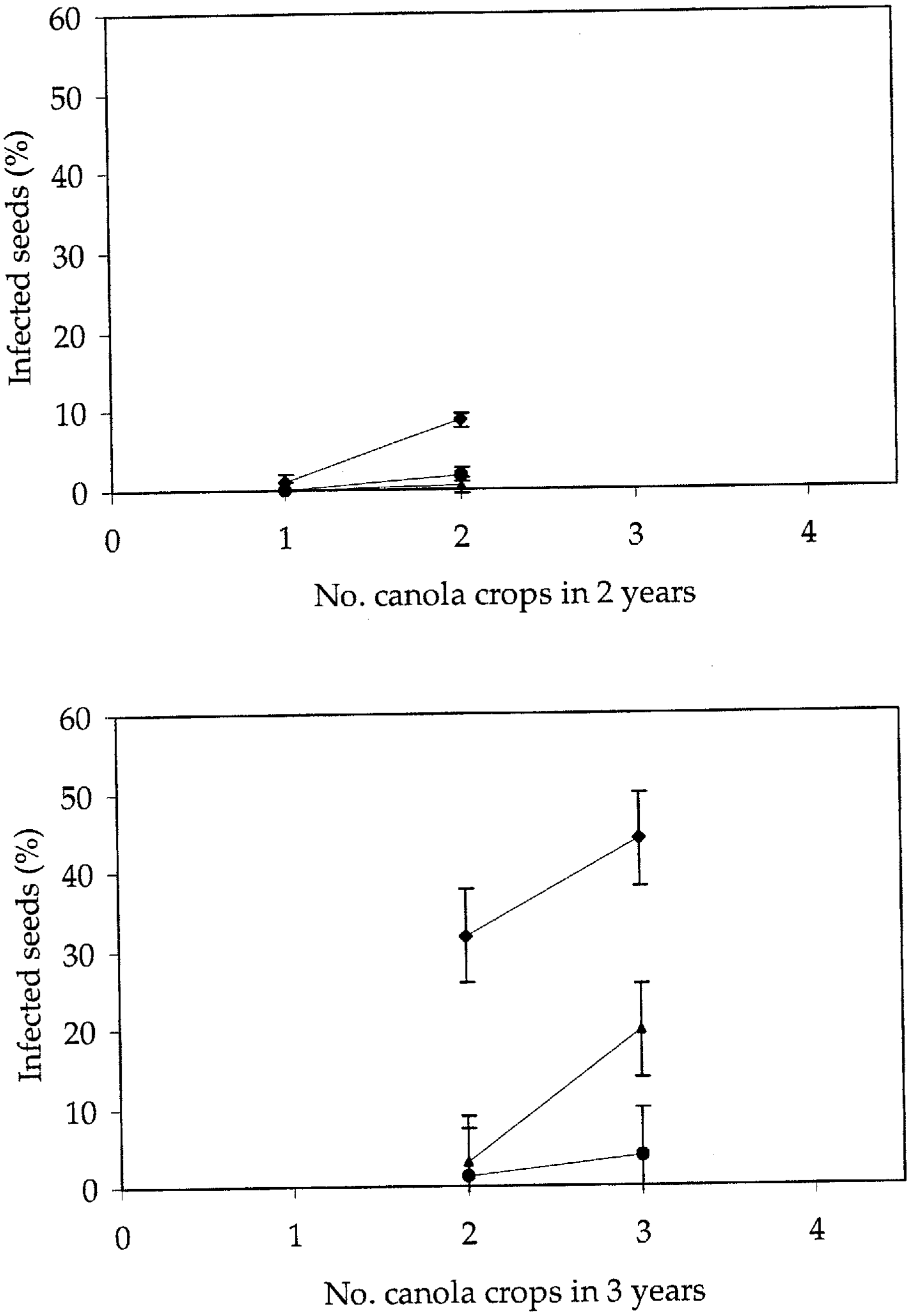


Figure 24. Effect of crop rotation on seed infection by *Leptosphaeria maculans* at Viking, AB in 1997 (top) and 1998 (bottom). Vertical lines indicate standard error of the mean. Each column represents the least-square mean percentage of 800 surface-sterilized seeds colonized by *L. maculans*. *B. napus* cvs. Westar (—▲—), Quantum (—●—) and *B. rapa* cv. Reward (—◆—) were included in the experiment.

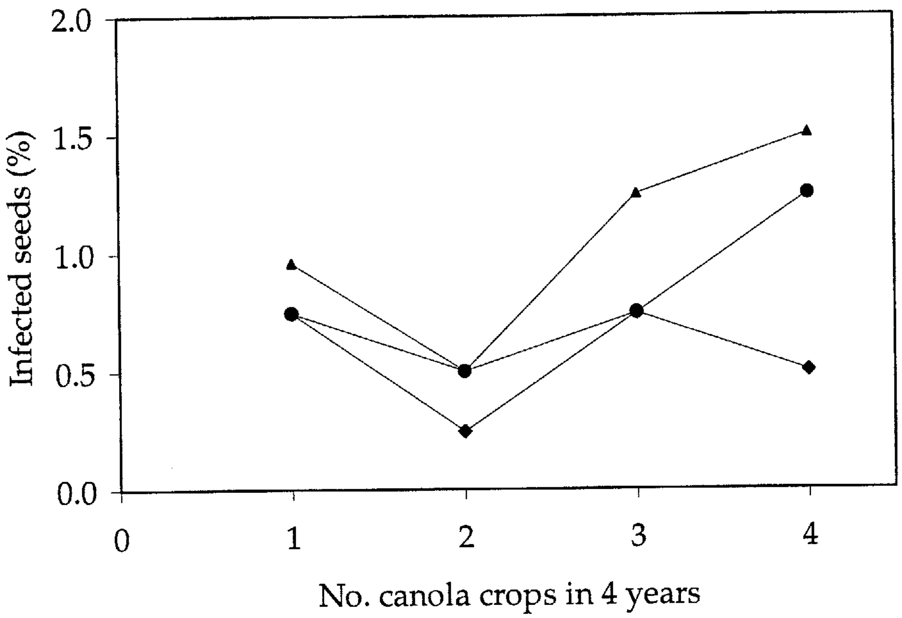


Figure 25. Effect of crop rotation on seed infection by *Leptosphaeria maculans* at Viking, AB in 1999. Each column represents the least-square mean percentage of 400 surface-sterilized seeds colonized by *L. maculans*. Standard error of the least-square mean was 0.5. Note that the scale of the Y-axis differs from that of Figure 24. *B. napus* cvs. Westar (—▲—), Quantum (—●—) and *B. rapa* cv. Reward (—◆—) were included in the experiment.

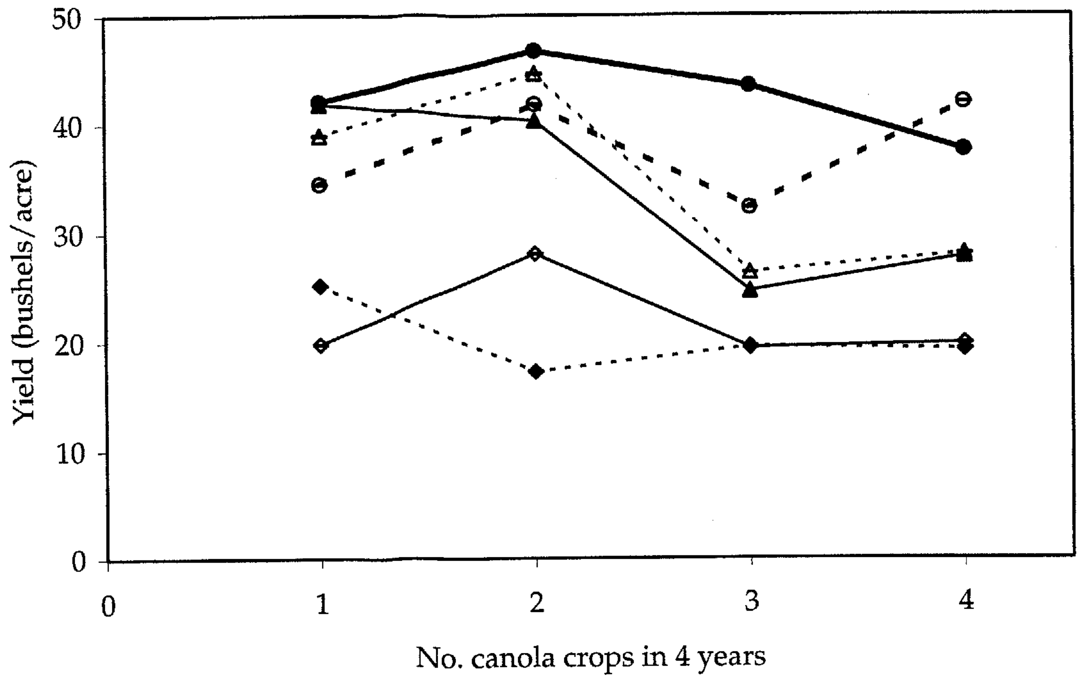


Figure 26. Effect of crop rotation on yield of three canola cultivars grown using conventional or reduced tillage at Viking AB in 1999:

—▲— Westar, reduced tillage;
- -△- - Westar, conventional tillage;
—●— Quantum, reduced tillage;
- - O- - Quantum, conventional tillage;
—◆— Reward, reduced tillage;
- - ◇- - Reward, conventional tillage.

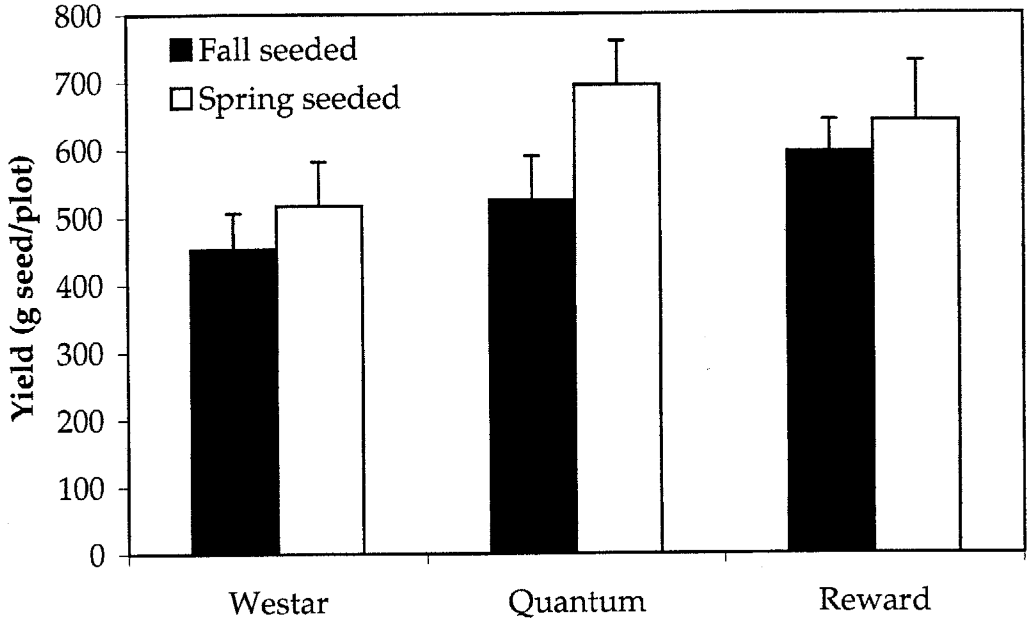


Figure 27. Effect of seeding date on yield of *Brassica napus* cv. Invigor 2153 seeded onto residues of three canola cultivars grown in the previous year. Plots were seeded on November 1, 1999 (fall seeded) or June 2, 2000 (spring seeded). Bars indicate the standard error of the least-square mean.

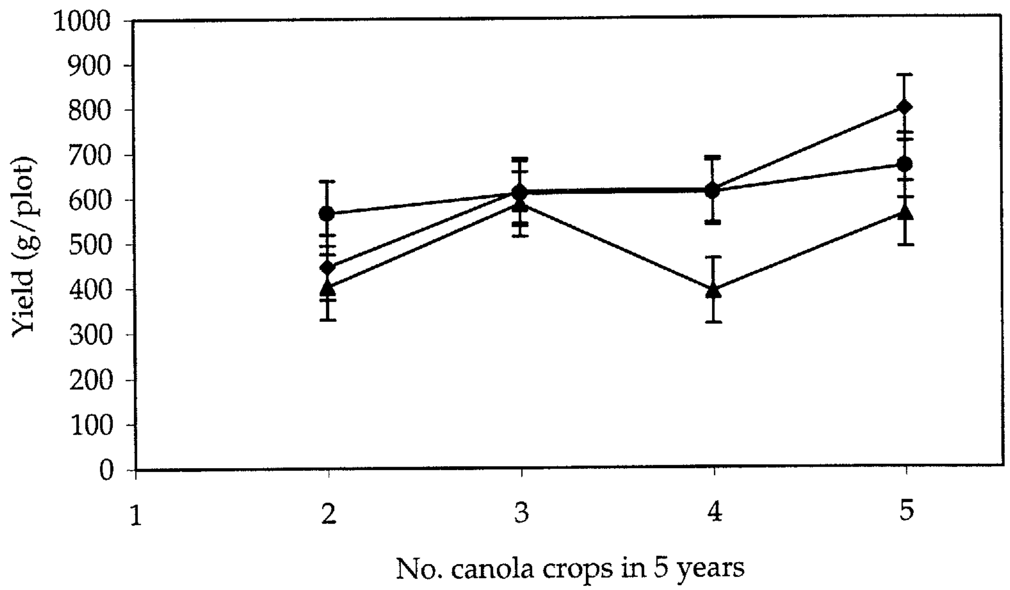


Figure 28. Effect of crop rotation on yield of *Brassica napus* cv. Invigor 2153 seeded onto residues of three canola cultivars grown in the previous year. Plots were seeded on November 1, 1999 (fall seeded) or June 2, 2000 (spring seeded). Bars indicate the standard error of the least-square mean. *B. napus* cvs. Westar (—▲—), Quantum (—●—) and *B. rapa* cv. Reward (—♦—) were included in the experiment.

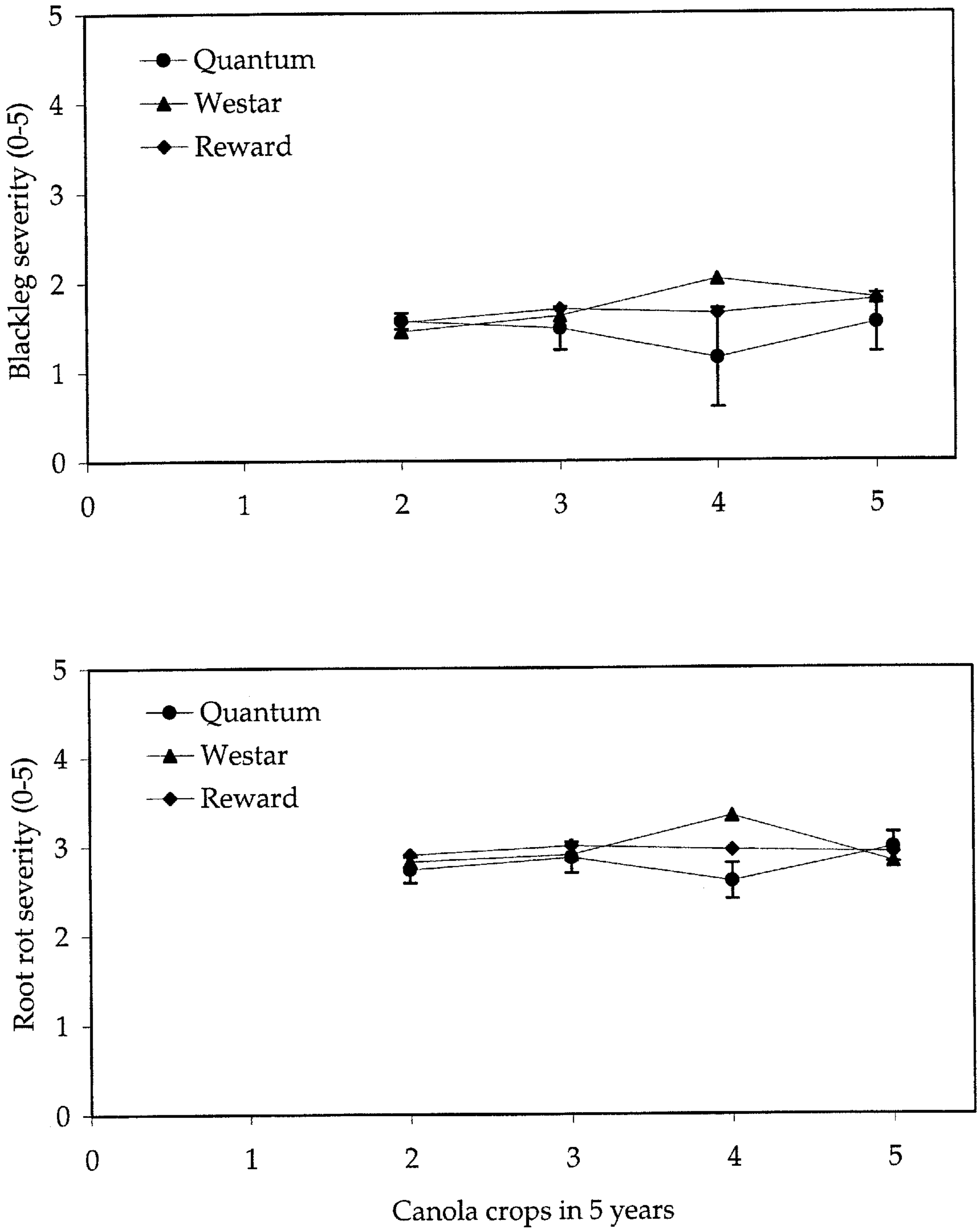
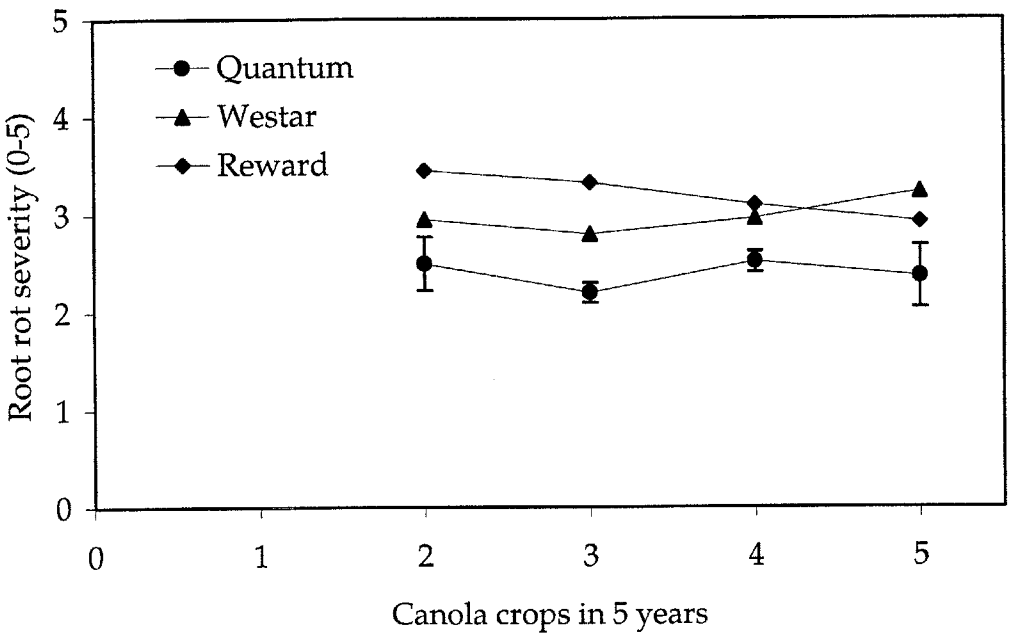


Figure 29. Blackleg and root rot severity of spring-seeded *Brassica napus* cv. Invigor 2153 at Viking AB in 2000. The cultivars Quantum, Westar or Reward were grown on the plots from 1996 through 1999. Vertical bars indicated standard error of the mean; standard errors of Westar and Reward were omitted for clarity.



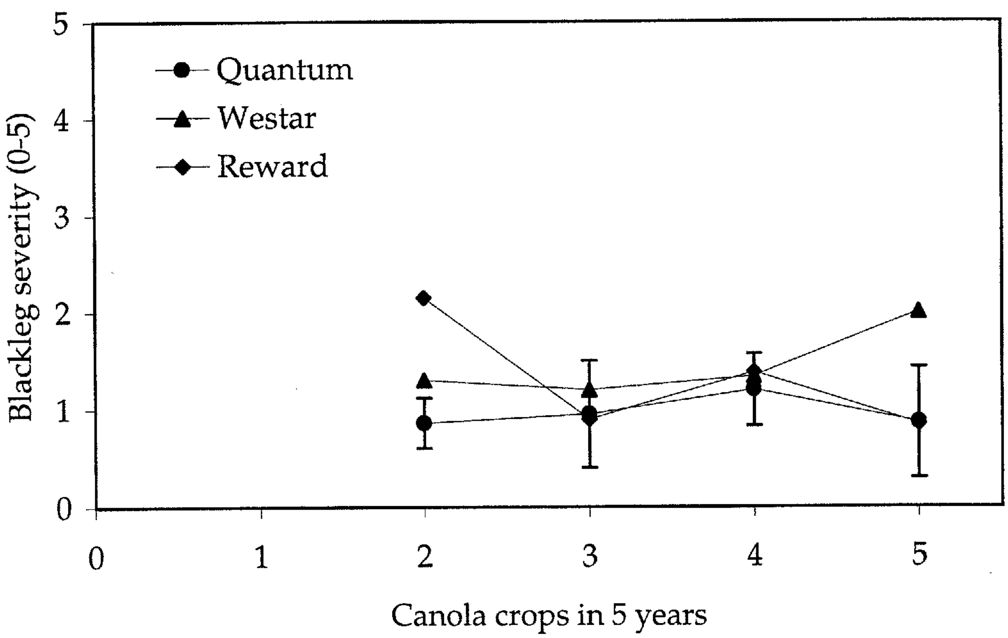


Figure 30. Blackleg and root rot severity of fall-seeded *Brassica napus* cv. Invigor 2153 at Viking AB in 2000. The cultivars Quantum, Westar or Reward were grown on the plots from 1996 through 1999. Vertical bars indicated standard error of the mean; standard errors of Westar and Reward were omitted for clarity.

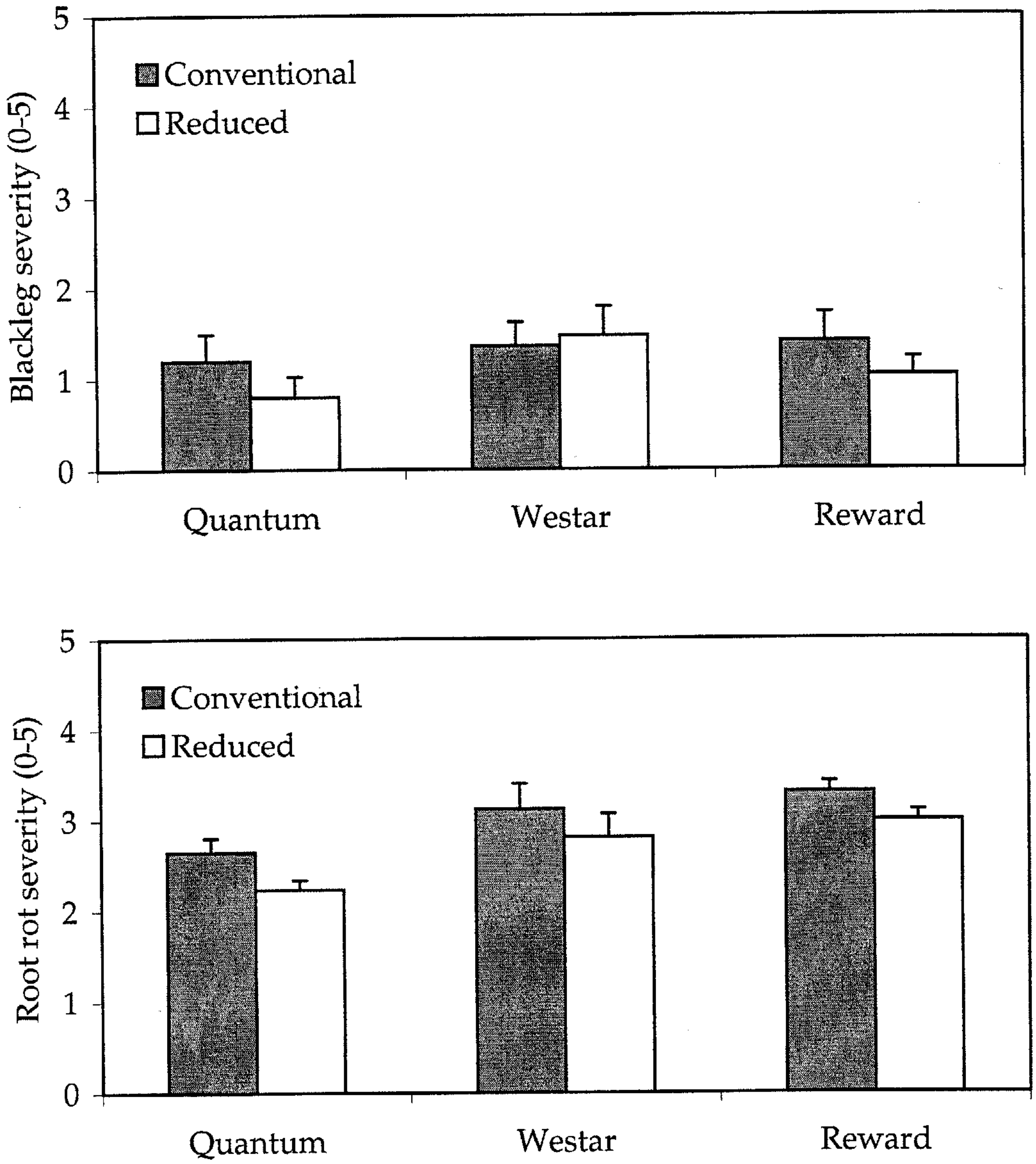


Figure 31. Effect of tillage method on Blackleg and root rot severity of fall-seeded *Brassica napus* cv. Invigor 2153 at Viking AB in 2000. The cultivars Quantum, Westar or Reward were grown on the plots from 1996 through 1999. Vertical bars indicate standard error of the mean; standard errors of Westar and Reward were omitted for clarity. Tillage treatments were retained from previous years of the study; columns therefore show the effect of tillage treatments applied in 2000.

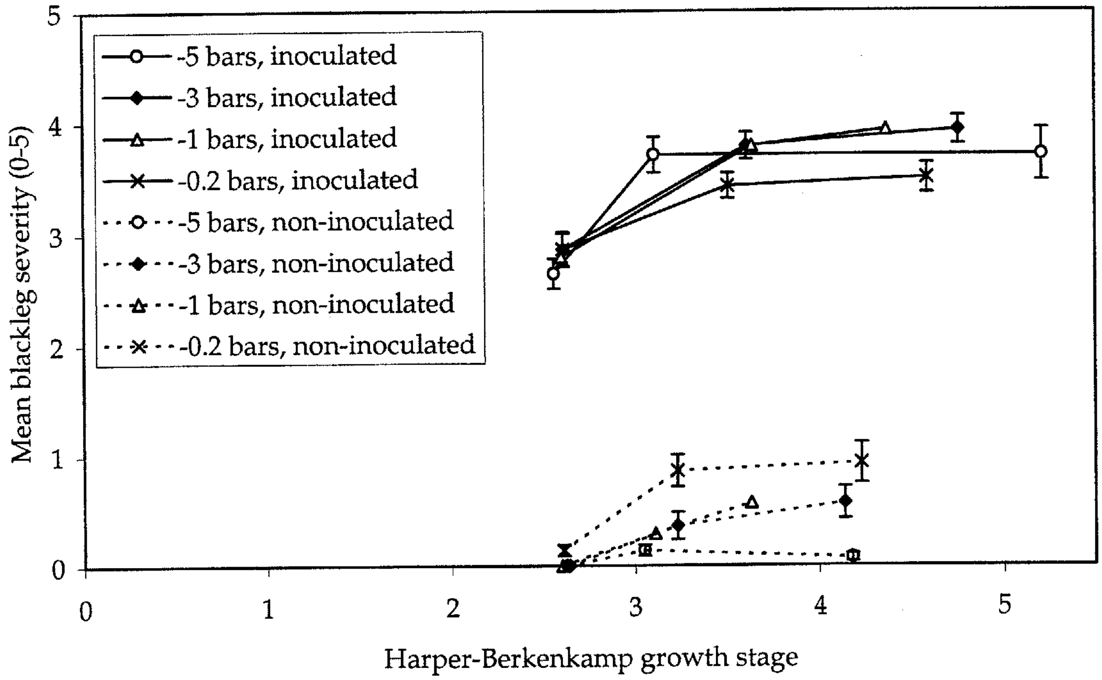


Figure 32. Effect of soil water potential on Blackleg disease severity of *Brassica napus* cv. Westar. Soil water potential was allowed to fluctuate between field capacity and four water potentials in a growth chamber experiment. Plants were sprayed inoculated with *L. maculans* pycnidiospores (1.0×10^6 spores•ml^{-1}); infection on uninoculated controls represents secondary disease spread.

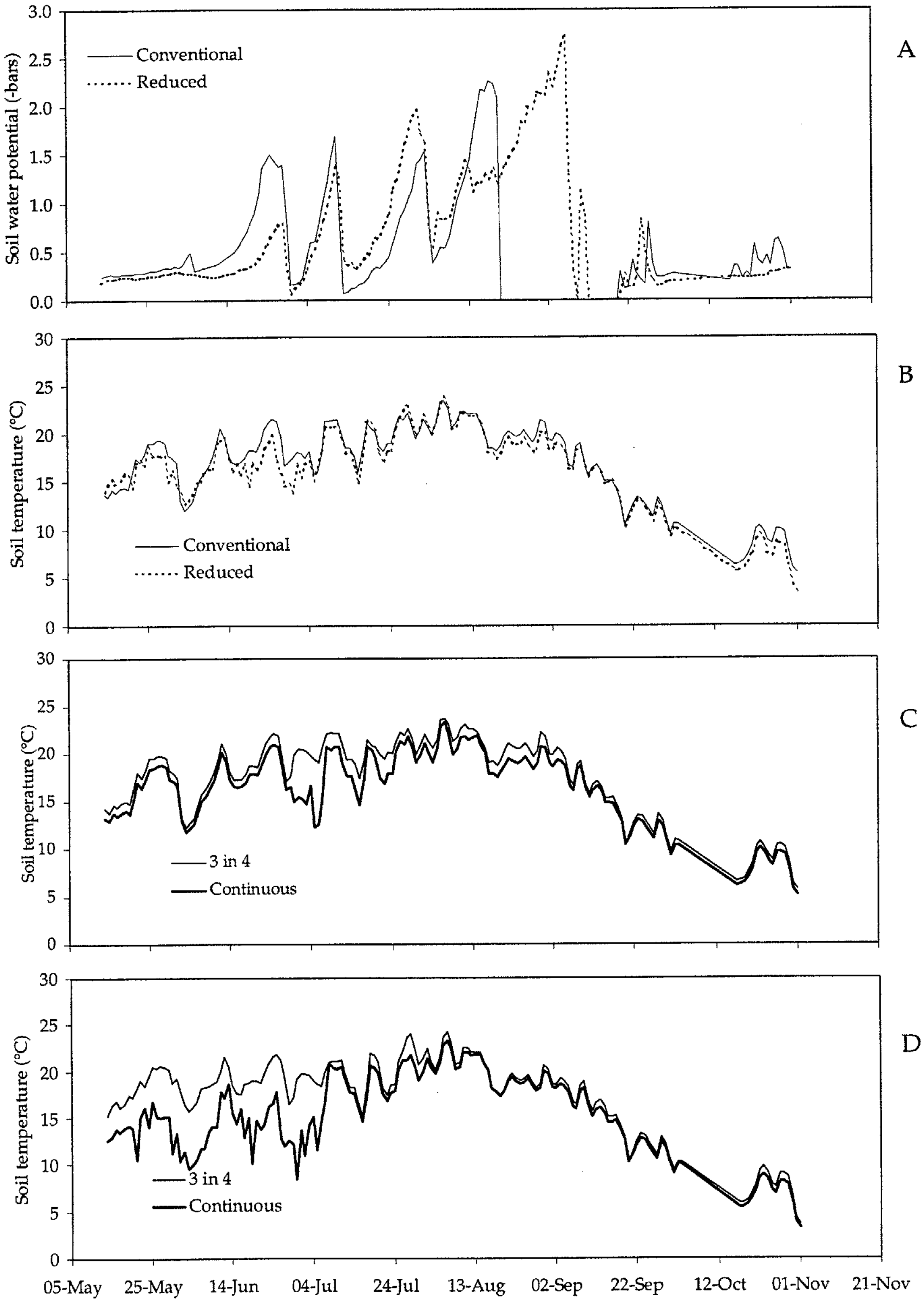


Figure 33. Average daily soil water potential (A) and temperature (B) 15 cm below the soil surface under two tillage systems at Viking AB in 1998. The bottom two figures compare average daily soil temperature in the two canola crops in four year and continuous canola rotation treatments under conventional (C) and reduced tillage (D).

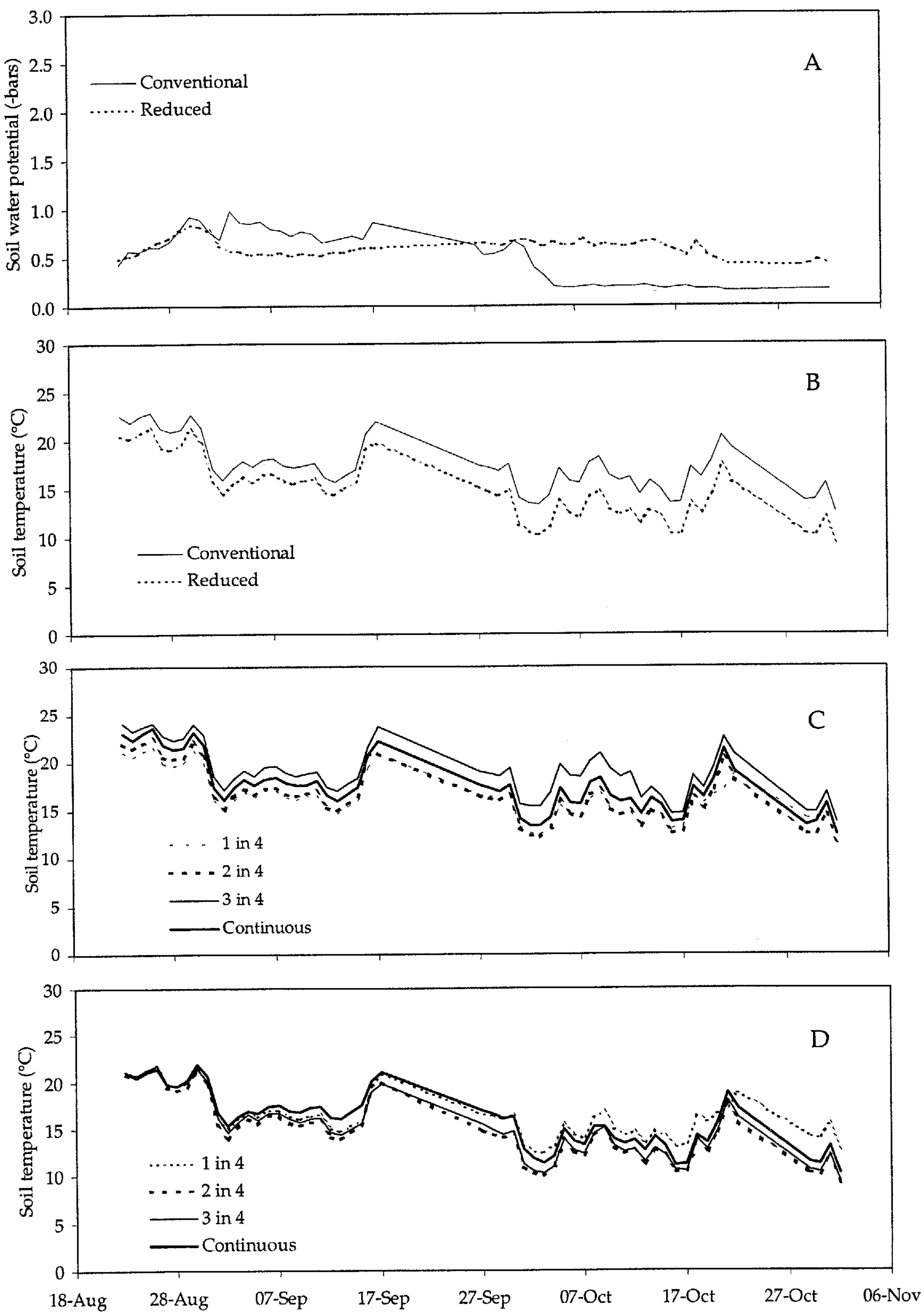


Figure 34. Average daily soil water potential (A) and temperature (B) 15 cm below the soil surface under two tillage systems at Viking AB in 1999. The bottom two figures compare average daily soil temperature in four rotation treatments (1 canola crop in 4 years, 2 canola crops in 4 years, etc.) under conventional (C) and reduced tillage (D).

APPENDIX 1: ANALYSIS OF VARIANCE OF DISEASE SEVERITY AND YIELD DATA.

	P>F					
Source	Yield	Blackleg severity	Blackleg incidence	Root rot severity	Root rot incidence	Black spot severity
Block (B)	0.0001	0.0016	0.0760	0.0058	0.0901	0.0407
Cultivar (C)	0.0012	0.0009	0.0711	0.0222	0.1182	0.0001
B x C	0.0001	0.0151	0.0003	0.0020	0.1213	0.0017
Tillage method (T)	0.2879	0.0219	0.1174	0.2236	0.7138	0.6038
C x T	0.1390	0.1337	0.1441	0.1403	0.8831	0.8313
C(Tx B)	0.1554	0.2387	0.0848	0.0151	0.3090	0.0001
Rotation scheme (R)	0.0001	0.0001	0.0001	0.0002	0.0635	0.0001
C x R	0.0001	0.0016	0.3477	0.0024	0.4015	0.0074
T x R	0.0008	0.4596	0.9612	0.8984	0.4775	0.1333
C x T x R	0.0141	0.8728	0.5909	0.3371	0.1620	0.0889
R^2	0.9242	0.8765	0.7643	0.7843	0.5819	0.9344
%C.V.	6.6471	9.0035	9.2954	8.5768	4.0455	24.3125

	P>F					
			Seed trans	Seed trans	Seed trans	Seed trans
Source	Emergence	Stand	Blackleg (1997)	Blackleg (1998)	Blackleg (1999)	Black spot (1997)
Block (B)	0.0001	0.2300	0.5896	0.1791	0.3309	0.0035
Cultivar (C)	0.0041	0.0037	0.0019	0.0133	0.5979	0.0120
B x C	0.0175	0.2984	0.6811	0.1166	0.1086	0.0099
Tillage method (T)	0.0161	0.0001	0.0045	0.0217	0.9313	0.0001
C x T	0.2663	0.0621	0.0102	0.0515	0.5170	0.3266
C(Tx B)	0.0001	0.3936	0.5647	0.6422	0.0598	0.5420
Rotation scheme (R)	0.0001	0.0838	0.0004	0.0431	0.3835	0.5661
C x R	0.4070	0.0236	0.0028	0.4843	0.9705	0.6417
T x R	0.0002	0.1058	0.0010	0.4502	0.7085	0.1203
C x T x R	0.0542	0.8672	0.0016	0.4890	0.2292	0.0371
R^2	0.8606	0.8030	0.8846	0.8240	0.4881	0.9138
%C.V.	0.8094	13.5803	32.2805	96.3678	168.4679	50.3795