Long-term survival and sporulation of *Leptosphaeria rnaculans* (blackleg) on naturally-infected rapeseed/canola stubble in Saskatchewan

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In semi-arid Saskatchewan, Canada, peak ascospore discharge by ***Leptosphaeria maculans*** from blackleg-infected rapeseed/canola ***(Brassica napus*** and ***B. rapa***) stubble residue generally occurred in the second year following the year of crop growth. Over 90% of the original stubble had disappeared by that time, leaving infected crowns and taproots that deteriorated slowly under the prevailing dry surface soil conditions. Ascospores of L. ***maculans*** continued to be discharged from this residue for a further **3-5** years, greatly exceeding the mean **3.3** year length of rotations out of rape followed by producers. Ascospore discharge from stubble residue could be intermittent, occasionally missing entire years. Burial or flooding of infected 19-month-old stubble for 10 days almost entirely eliminated the production of ascospores. Rape stems with severe basal cankers produced L. ***maculans*** ascospores earlier and in greater numbers than did stems with extensive superficial lesions taken from the same field.

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Dans les conditions semi-arides de la Saskatchewan (Canada), la période de pointe d'éjection des ascospores, attribuable à ***Leptosphaeria maculans*** sur les résidus de chaume de Canola infectés par la jambe noire, se produit habituellement pendant l'année suivant la recolte. À ce moment, plus de 90 % du chaume original avait disparu, laissant des couronnes et des pivots infectes qui se sont détériorés lentement étant donne les conditions de sol sec à la surface. L'ejection d'ascospores de L. ***maculans*** à partir de ces residus s'est poursuivie pendant **3** à 5 ans, depassant largement la durée mayenne de rotation de **3,3** ans, sans colza, que les producteurs ont adoptée. L'éjection d'ascospores dans les residus de chaume peut &re intermittente. Il arrive occasionnellement que des années complètes en soient épargnées. L'enfouissement ou l'immersion pendant 10 jours de chaume infecté, vieux de 19 mois, a pratiquement éliminé toute production d'ascospores. Les tiges de colza présentant des chancres basilaires importants ont produit plus rapidement et davantage d'ascospores de L. maculans que ne l'ont fait les tiges portant de larges lesions superficielles dans le même champ.

Introduction

The virulent form of ***Leptosphaeria maculans*** (Desm.) Ces. & de Not. has become endemic in the parts of Saskatchewan where rapeseed/canola ***(Brassica napus*** L. and B. ***rapa*** L.) is grown **(14).** After harvest the fungus develops saprophytically on stubble of both blackleg-susceptible and resistant cultivars of ***Brassica*** spp. (8). Elimination or neutralization of infected stubble is of prime importance in blackleg control strategies. Ascospores produced on stubble are the most important agents of infection of canola crops in Canada (12) and abroad **(5,17).** Genetic recombination of the fungus on stubble may produce pathotypes capable of attacking important sources of genetic resistance, such as ***Brassica juncea*** (L.) Coss. Such pathotypes have already been found in Australia (3). Long-term survival of L. ***maculans*** on canola stubble residue in the semi-arid Saskatchewan environment has not been studied in depth. In Australia, over 90% of the residue of a rapeseed crop disappeared during the first **12** months following harvest **(11).** However, ascospores continued to be produced on the remaining crop debris for at least three years after harvest **(11).** In France, infected pieces of rapeseed stubble were found in some fields for at least seven years **(16).**

The virulent form of ***L. maculans*** has been slow to spread into northern canola-producing parts of Saskatchewan from areas farther south **(14).** This is likely due, in part, to more moist conditions in the north that permit more frequent field cultivation, more complete burial of trash, and hence its accelerated decomposition. Water frequently stands in depressions in producers' fields for considerable periods every spring because drainage is impaired by frozen underlying soil. The effect of flooding on infected stubble is not known.

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Objectives of this study were: (1) to examine the effect of cropping practices in central Saskatchewan on blackleg severity and on the rate at which canola stubble disappeared from farm fields; (2) to examine the effect of the immersion in water or burial of ascospore-producing canola stubble on spore production; (3) to examine the possibility of resumption of ascospore production on apparently "spent" material.

Materials and methods

Survey. From 1977–94, crop rotations and the incidence of blackleg were recorded for a total of 100 fields in 11 rural municipalities around Saskatoon (15). Sixty of the 100 fields were seeded to canola in May of 1994 and after harvest these fields were surveyed for blackleg as previously described (15).

Flooding. The effect of artificial flooding of naturally-infected 1-year-old stems of *B. napus* on ascospore production by the virulent form of *L. maculans* was studied in 1992. Thirty samples of 18 6-cm segments of basal stem were prepared from stubble collected March 27, 1992. Initial sporulation levels were determined on March 31 using ascospore liberation tunnels (7). Air flow through each tunnel was adjusted to 13,000 cc/min using a Rotameter (Brooks Rotameter Co., Lansdale, PA). The stems were moistened with water and ascospores caught on vaseline coated microscope slides for 1.5 hours. Spores were stained with cotton blue in lactophenol (1). Spore numbers were expressed per 10 g stubble per 1.5 h. The individual samples were placed in transparent plastic containers 11 cm dia. x 13 cm high, each fitted with a wire grid 7.2 x 8.0 cm to keep the stems immersed. Four hundred mL of deionized water were added to each, except the controls, and the grids adjusted so that the stem pieces were covered by 3 cm of water. Five lots of 18 stem pieces each were immersed for 0, 1, 3, 6, 10 or 15 days, the water was removed, the stems were placed outdoors and 4, 8, 14, 18 and 26 weeks later were tested for ascospores. The stems were returned outdoors for the winter and retested in June, 1993. Spore numbers were transformed to natural logarithms and the data analyzed using the SAS GLM statistical package procedure (SAS Institute Inc. 1989).

Burial. Samples of naturally-infected canola stubble were buried 3-4 cm deep in a sandy loam soil with a field capacity (F.C.) of 30.7%. The time required for cessation of sporulation was determined at soil moisture levels ranging from 13–70% F.C. Ascospore discharges prior to and after periods of burial were measured as previously described. The soil and stems were kept in wooden flats lined and covered with aluminum foil and maintained at 20–25°C. Control samples were left exposed to the air in 10-cm plastic pots on the soil surface. Samples, once dug up, were not reburied.

Lona-term survival studies. Selected producers' fields were sampled at least once annually for four or more years. Standing stubble in six 1-m^2 quadrats was pulled, air-dried, counted and weighed. Subsequently the fields were resampled by removing the top 5 cm of soil in six 1-m^2 quadrats per field and passing it through a wire sieve having a 0.5 cm mesh. The rape stubble residue present in each quadrant was weighed, the number of pieces counted, and the number of ascospores present / 10 g stubble / 1.5 hours determined. Studies of longer duration started with 7 to 19-month-old naturally infected canola stubble and were continued for seven years or more. Initially, material collected in April was cut into 6-cm lengths, each piece including a portion of the taproot. Samples were stored outdoors in well-drained wooden flats. Every year spore discharge was tested monthly from April to October.

Preliminary experiments indicated that severely cankered stems produced more ascospores over a longer period than stems having relatively mild symptoms. Collections were made from two crops infected by the virulent strain of *L. maculans,* one grown in 1990 and the other in 1991. Material from each field was divided into stems having superficial lesions and those with severe basal cankers. Material was incubated outdoors and was tested for ascospore discharges once monthly from June to September, starting in the year after crop growth.

Results

Survey. Of the total crops grown in the 100 fields over 17 years, 46.5% were cereals and 22.1% were *Brassica* crops, chiefly rapeseed/canola. Other crops made up 7% and summerfallow, 24.4% (Fig. 1). Eighty-four percent of the fields were fallowed in the year preceding a canola crop, while 87% of the crops following canola were cereals (Fig. 2). Thirty fields had three or more canola crops during the study. On average, 2.1 years elapsed between canola crops 1 and 2, 3.4 years between canola crops 2 and 3, and 2.9 years between crops 3 and 4. For 80 fields the mean number of summerfallow years between 1984 and 1988 and between 1989 and 1993, was 1.4. Although some producers had adopted continuous cropping, this practice was not common in the fields surveyed.

A three-year rotation (two years out of canola) was the most common one in the 60 fields surveyed in the autumn of 1994 (Table 1). The mean overall blackleg incidence was highest (97.7%) in fields with a 2-year rotation. Mean blackleg incidence still exceeded 63% in fields which had not grown canola for 6-12 years. Two fields which had not grown canola for 12 years had incidences of 90%. However, the mean percentage of severe basal stem cankers declined sharply after one year and remained relatively low when fields were out of canola for three or more years (Table 1). Some results for individual fields are shown in Fig. 3. In

general, the incidence of virulent blackleg increased in successive canola crops grown in the same field if they were separated in the rotation by one to three years. When they were separated by five or more years, the incidence of blackleg usually declined sharply. Field 11 is an example of relatively short intervals between canola crops, and fields 6 and 25 illustrate the results usually seen with longer rotations of four to six years. Exceptions to the pattern were seen. Although seven years elapsed between the second and third canola crops in field 80, the incidence of the weakly virulent strain commonly found on canola increased greatly in crop 3 and incidence of the virulent strain remained unchanged (Fig. 3).

Flooding. Prior to flooding, the pathogen produced approximately 4,000 ascospores per 10 g stubble per 1.5 h. Immersion in water for six days or more permanently reduced ascospore discharge to very low levels (Table 2). Samples immersed for three days showed a temporary increase in sporulation eight weeks after flooding but spore production was erratic. The numbers of ascospores discharged by the five replicate samples ranged from 6406% of those recorded prior to treatment. Sporulation in samples immersed for one day recovered slowly to greater than pre-flooding levels, producing more spores than the controls at 18 and 26 weeks after treatment. However, 15 months after flooding, sporulation in all samples had dropped below pre-treatment levels. Even ascospore production in the I-day treatment exhibited a much greater decline than the controls. Statistically significant differences were found between treatments and dates. Results for all treatments except one day's flooding were significantly different from the unmoistened checks (Table 3).

Burial. Immediately prior to burial in soil, samples discharged between 1,000 and 6,000 ascospores per hour. Those samples retested following burial for 24 h showed an increase in spore numbers of up to 400%, regardless of soil moisture content. This was commonly observed and is attributed to the moistening required for the initial test of spore numbers prior to burial. At soil moistures of 40–70% F.C., spore discharge declined sharply by the fourth day after burial and depletion occurred in 10-13 days. L. ***maculans*** did not recover its ability to produce ascospores after these samples were removed from the soil. Spore release from samples buried in soil of 13–20% F.C. and from exposed control samples remained at high levels for six weeks. Depletion at 13–20% F.C. took 105 days or more. Several weeks' burial of fresh infected stubble on which production of ascospores had not started completely prevented their formation.

Lona-term survival. The rate of loss of surface stubble residue from field 12 was typical of that in many fields sampled between 1981 and 1990. Stubble residue from a 1978 rape crop was present in field 12 when a second rape crop was grown in 1981. In May, 1982, an average 8.2 ± 3.3 g/m^2 of 1978 residue remained and this declined to 5.8 ± 2.3 g/m^2 by the fall of 1982. Small numbers of ascospores (approximately 10/10 g stubble/1.5 h) were discharged from this material in 1982. The amount of 1981 stubble remaining on or near the soil surface declined rapidly under normal cultivation practices (Fig. 4). An initial cultivation of standing stubble reduced the weight of surface trash/m^2 by 55% (Table 4). Twenty-four months after the crop was harvested only 10% by weight of the original stubble remained. The mean number of ascospores produced by the stubble in field 12 per m^2 24 months after harvest was 0.1% of that produced 13 months after harvest. However, it is important to note that spore numbers fluctuated over the growing season each year, being higher in May-June and lower in July-August (Table 4). Sporulation continued on the 1981 stubble for at least four years. It was sufficient to cause heavy infection in a 1984 crop in field 12 and substantial stand reduction in portions of a neighbouring rape crop planted in 1985. The percent incidence of infection in the 1984 crop was 96.5 ± 2.7 and the average estimated percent yield **loss,** 69.4 ± 2.0. The mean weight of stubble/m^2 in August, 1984, was 168.4 ± 28.6 g. This had declined to 100.8 ± 26.9 g one year later, a reduction of 40.1%. Twenty-three months after the crop 25.9% of the stubble remained, and 33 months later, 12.3%.

The amount and seasonal timing of sporulation recorded in field 12 and in many others was more than sufficient to bridge the interval between successive rape crops. Field 10 grew its last rape crop in 1981. The disappearance of rape stubble from this field mirrored that in field 12. Blackleg-infected rape stubble was collected from the soil surface in field 10 over the following 10 years. Ascospore discharges were obtained from freshly collected rape stubble residue as late as 1989.

Ascospore production by L. ***maculans*** on stubble residue at the soil surface generally reached its maximum level in the second year after crop growth and declined thereafter. When conditions were unfavourable to the initiation of ascospore production in the year after crop growth, as in 1987 and 1988, maximum sporulation was often not achieved until the third year after a rape crop (Table 5). Numbers of spores usually had dropped to low levels or sporulation had ceased by the fifth year after crop growth, although occasionally sporulation continued in the sixth or seventh year. In field 11, residue from at least two rape crops, grown in 1986 and 1989, produced ascospores simultaneously for at least three years (1990–92). Sporulation on residue of the 1989 crop stopped before that on residue of the 1986 crop. Sporulation on the latter had built up to a peak more slowly (Table 5).

Several examples were found where sporulation ceased on stubble that was continually exposed, only to resume later (Table 6). In 1983 material from field 7; sporulation stopped

in August 1986, but resumed in May 1987. Little or no sporulation then occurred on the material in 1988, but ascospores were again detected in July, 1989. The mean number of ascospores discharged in early July, 1987 / 10 g residue / 1.5 h was 363 ± 343 (range: 38–853). In early July, 1989, it was 15 ± 17 (range: 1–37).

Blackleg severity in a crop has important implications for long-term inoculum levels originating from the residue of that crop. Ascospores were discharged earlier and in greater numbers in the year after crop growth from severely cankered stubble plants than from stubble with extensive superficial lesions taken from the same field (Table 7). This relationship continued in subsequent years. For example, in 1992 the average number of spores produced on eight trapping dates by severely cankered 1990 material/10 g residue/1.5 h was 4,973± 793, and by lightly cankered material 2,676± 577. The more severely cankered stems likely had been the earliest infected, although they could have represented more susceptible plants within the population.

Discussion

It is evident that in Saskatchewan's semi-arid environment, blackleg-infected canola stubble residue may continue producing ascospores for 5–7 years, much longer than the average rotations out of canola practiced by producers. Although 90% of the original stubble frequently had broken down after two years, and by the fifth year after crop growth spore production was generally low, sufficient spores produced at critical times were present to perpetuate the disease at a high level. Unlike the situation in Australia (11) and parts of Europe (5), infected canola residue more than two years old plays a major role in the epidemiology of blackleg in Saskatchewan. Where the surface soil is dry much of the time, rotations would have to be unreasonably long to completely eliminate stubble-borne inoculum. The fact that ascospore production on stubble residue can be intermittent often makes it difficult to predict the subsequent course of sporulation. Rotations longer than three or four years out of canola are economically unattractive to producers. However, avoiding planting canola on 2- or 3-year-old *Brassica* stubble may substantially reduce the severity of blackleg in the next canola crop. The fields with long rotations (up to 12 years) out of canola likely were contaminated by ascospores carried by wind from adjacent fields having blackleg-infected canola stubble residue.

Crop rotations practiced in the study area continued to be traditional ones, with summerfallow in the year preceding canola to permit good seedbed preparation and a cereal following canola to facilitate chemical control of volunteer canola and other broadleaved species. Rotations recently have been augmented by legumes and other specialty crops, mainly lentils (*Lens culinaris* Medik). Twenty years ago, the suggested rotation involving rapeseed in western Canada was rape-cereal-summerfallow-rape. With the advent of virulent blackleg, three or more years between rapeseed/canola crops were recommended. These longer rotations have been generally adopted by producers, although the present study indicates that four to six years between canola crops are preferable to three. Rotations out of canola may now be shortening again given the relatively high monetary value of canola and the availability of *B. napus* cultivars with improved blackleg resistance. The replacement of older blackleg-susceptible cultivars such as Westar has resulted in reduced blackleg incidence in *B. napus* relative to *B. rapa* cultivars (15).

Flooding of infected stubble, even for relatively short periods, irreparably damaged the pathogen's ability to produce ascospores. This may be a natural means whereby inoculum levels of *L. maculans* are reduced in the field, as water has been observed to stand in large parts of some fields for periods in excess of 15 days. Burial of stubble in soil having a moisture content of over 40% F.C. was effective in eliminating ascospore production over a time span similar to that of the flooding experiment. The effect also appeared to be irreversible. Spore release from samples buried in soil of 13–20% F.C. declined after six weeks. Therefore, despite fluctuations in soil moisture content, infected stubble buried at the time of spring seeding should be depleted of ascospores by autumn. Infected stubble that is buried during fall cultivation should be depleted by the time of seeding the following spring, after being subjected to autumn rains and melting snow in early spring.

Plowing under the remains of a severely diseased broccoli crop resulted in a 67% reduction in blackleg in the succeeding broccoli crop (6). This, however, is not a practical solution to the blackleg problem for western Canadian producers, who, of necessity, are increasingly adopting minimum tillage to conserve moisture and soil. Others have questioned whether burial of stubble is a fully effective means of blackleg control. An Australian study (10) found that 67% of residues buried for 18 months produced fructifications of *L. maculans* when placed under black light. In France, stubble residue still contained ascocarps of *L. maculans* which were capable of producing spores after two to four years' burial (2).

Deep burial of stubble followed by shallow cultivation is a means of avoiding re-exposing infected residue (10). However, some material would inevitably escape burial. Even small amounts of residual stubble could produce sufficient numbers of ascospores to initiate scattered primary infections throughout a crop. Subsequently, pycnidiospores from the primary lesions could cause a blackleg epiphytotic under favourable environmental conditions (4). This may

explain some blackleg outbreaks in Saskatchewan fields (Fig. 3) following long rotations out of canola.

As the use of cultivation to control blackleg runs counter to present recommendations, chemical treatment of infected stubble has been suggested as an alternative (5). A number of fungicides, herbicides and surfactants applied to stubble before pseudothecial formation were more than 90% effective in preventing further development (9). They also stopped ascospore production when applied to stubble bearing mature ascocarps. However, the effectiveness of treatments on a field scale, possible contamination from adjacent untreated fields, the economic viability of such treatments, and their environmental implications must be fully evaluated.

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Table 1. Effect of length of rotation on incidence and severity of blackleg (*Leptosphaeria maculans*) in central Saskatchewan.*

	Number of growing seasons between canola crops						
	1	2	3	4	5	6–8	9–12
% fields in each category	8.3	30.0	15.0	11.7	8.3	11.7	15.0
Mean blackleg incidence (1994)	97.7	88.1	82.0	81.9	65.0	69.2	63.2
Range	95.0–100.0	71.7–98.8	47.1–100.0	55.0–96.7	38.3–88.3	40.4–100.0	10.0–90.0
% severe basal stem cankers	42.6	11.9	4.1	3.1	1.0	0.5	0.9
Range	1.7–72.0	0.0–58.8	0.0–21.7	0.0–8.3	0.0–3.3	0.0–1.7	0.0–5.0

* Results of 1994 survey of 60 canola stubble crops in fields of known cropping history.

Table 2. Effect of immersion of blackleg-infected rape stubble in water for from 0 to 15 days on subsequent ascospore production by the virulent strain of *Leptosphaeria maculans*.

No. days immersed in water	Weeks or months after flooding and ascospore production (% of number prior to flooding)*					
	4	8	14	18	26 weeks	15 months
0	68.30	123.88	111.50	94.10	225.84	61.11
1	88.00	79.38	62.48	133.70	252.06	29.98
3	15.42	112.66	30.90	48.84	67.02	15.43
6	0.70	12.68	5.00	4.66	7.56	1.99
10	0.00	0.00	0.03	0.00	0.01	0.93
15	0.00	0.02	0.05	0.00	0.03	0.32

* Ascospore production prior to flooding averaged approximately 4000/10 g/1.5h.

Table 3. ANOVA of Log (no. spores + 0.5) showing the effects of length of flooding treatment and time elapsed after treatment on spore numbers, and linear contrasts of various flooding treatments.*

Source	df	Mean square	F value	Pr > F
Replicate (R)	4	7.8412	3.90	0.0169
Treatment (T)	5	315.1234	156.65	0.0001
Error a	20	2.0166		
Date (D)**	5	81.0513	130.03	0.0001
Interaction T X D	25	14.2846	22.92	0.0001
Error b	120	0.6234		

Contrasts*	df	Mean square	F value	Pr > F
0 vs remainder	1	350.3845	174.18	0.0001
0,1,3 vs 6,10,15	1	1276.1938	634.41	0.0001
0, 1 vs 3,6	1	275.1056	127.81	0.0001
0 vs 1	1	2.8837	1.43	0.2452
0 vs 3	1	49.1222	24.42	0.0001
0 vs 6	1	195.1426	97.01	0.0001
Error a		2.0116		

* Contrast of treatments: 0 = non-immersed control; 1, 3, 6, 10, 15 = number of days blackleg-infectedstubble immersed in water.
** Dates = time elapsed after treatment (See Table 2).

Table 4. Breakdown of 1981 rape stubble in a commercial field (#12) and reduction in number of ascospores of Leptosphaeria maculans released, 1982–85.

Amount of 1981 stubble residue and sporulation	Sampling date and crop grown							
	April,[1] 1982	May,[2] 1982	Sept., 1982	August, 1983	June, 1984	August, 1984	May, 1985	Sept., 1985
		cereal		none		rapeseed		cereal
Average weight (g/m^2)	163.0 ±27.7	73.9 f11.8	51.7 f17.8	15.4 f7.9		6.6 ±2.6		6.2 f1.5
% of original weight	100.0	45.3	31.7	9.5		4.0		3.8
No. stubble pieces	96.2 ±18.9	44.8 f8.2	35.2 f13.3	30.0 f10.2		25.0 f7.6		34.7 f5.9
% of original number	100.0	46.6	36.6	31.2		26.0		36.1
Average weight/piece (g)	1.70 ±0.22	1.66 ±0.21	1.47 f0.49	0.45 ±0.09		0.26 ±0.07		0.18 ±0.03
Average number ascospores /10 g stubble/1.5 h	0.0	0.0	7574 ±5896	29 f43	985 ±1476	11 ±18	152 ±209	33 f72
Average number spores $/m^2/1.5$ h	0.0	0.0	51017 ±49190	54 f76		9 f15		19 k43
Highest number spores $/m^2/1.5$h	0.0	0.0	122799	196		42		116

[1]Standing stubble. [2]Stubble worked up once.

Table 5. Annual peak discharge of ascospores by *Leptosphaeria maculans* over seven years from infected rape stubble residue exposed on the soil surface.

Year crop grown	Year after crop grown and mean no. ascospores discharged X 10^3 /10 g residue/1.5 h ± s.d.						
	1	2	3	4	5	6	7
1979	3.33 ± 1.49	11.47 ± 4.28	0.38 ± 0.22	0	0	0	0
1980	3.77 ± 3.68	2.29 ± 0.62	0.12 ± 0.08	Another rape crop in year 3			
1983	0	0.04 ± 0.04	0.14 ± 0.09	0.16 ± 0.07	<0.01	0.02 ± 0.02	<0.01
1984	0.11 ± 0.03	0.83 ± 0.22	3.23 ± 0.99	0.01	0.02	<0.01	0
1985	<0.01	1.21 ± 1.11	0.85 ± 1.99	1.87 ± 2.87	0.26 ± 0.37	0.21 ± 0.28	
1985	<0.01	2.29 ± 1.87	0.13 ± 0.25	0.60 ± 0.49	<0.01	<0.01	0
1986	0.70 ± 0.45	0.07 ± 0.09	2.32 ± 0.61	<0.01	<0.01	0	0
1986[1]	1.54 ± 0.96	1.55 ± 1.29	17.12 ± 7.14	3.12 ± 0.62	0.96 ± 1.08	0.14 ± 0.18	0.15 ± 0.16
1987	0	0.54 ± 0.32	2.57 ± 2.38	0.20 ± 0.45	<0.01	<0.01	0
1987	<0.01	3.66 ± 1.55	0.05 ± 0.04	<0.01	0	0	0
1988	5.35 ± 1.72	13.37 ± 7.77	10.51 ± 2.46	1.52 ± 2.10	0.63 ± 0.54	--	--
1988	28.15 ± 9.70	8.92 ± 2.45	2.19 ± 1.17	0.06 ± 0.05	<0.01	--	--
1989[1]	4.13 ± 1.59	11.57 ± 6.82	<0.01	0	--	--	--
1990	10.80 ± 2.56	26.46 ± 5.49	1.67 ± 0.42	New rape crop in year 3			

[1] Field 11 (See text).

Table 6. Intermittent production of ascospores by ***Leptosphaeria maculans*** from 1983 rapeseed stubble residue exposed on the soil surface.

Field	Year	Month and % samples' discharging >1 ascospore /10 g residue/1.5 h					
		May	June	July	August	September	October
7	1984		0	0	0	0	50
	1985	100	100	100	100	100	100
	1986	100	100	100	40	0	0
	1987	100	100	100	80	60	
	1988	0	0	0	0	20	
	1989	0		80	100		
16	1984	0	0	0	0	50	0
	1985		50				
	1986	0	75	50	25	0	
	1987	0	0	0	0	40	
	1988	0	0	20	40	80	
	1989	100		100	80		

'Maximum number of samples = 5.

Table 7. Ascospore discharge by ***Leptosphaeria maculans*** from slightly and severely cankered stems of ***Brassica napus*** taken from the same field.

Year crop grown	stem canker severity	Mean numbers of ascospores discharged* /10 g stubble/1.5 h ± s.d.			
		June	July	August	September
1990	severe**	0	4,711 ±1,182	5,304 ±2,407	3,188 ±2,819
1990	slight**	0	571 f372	1,571 f892	1,553 f386
1991	severe	0	182 ±370	333 ±239	2,243 ±1,714
1991	slight	0	0	201 f164	926 ±1,069

* Mean of five replicate samples, each consisting of 20 basal stem segments seven cm long. Data are for one trapping date per month in the year after crop growth.

** Differences between means for "severe" and "slight" for July and for August significant at P 4 0.05.

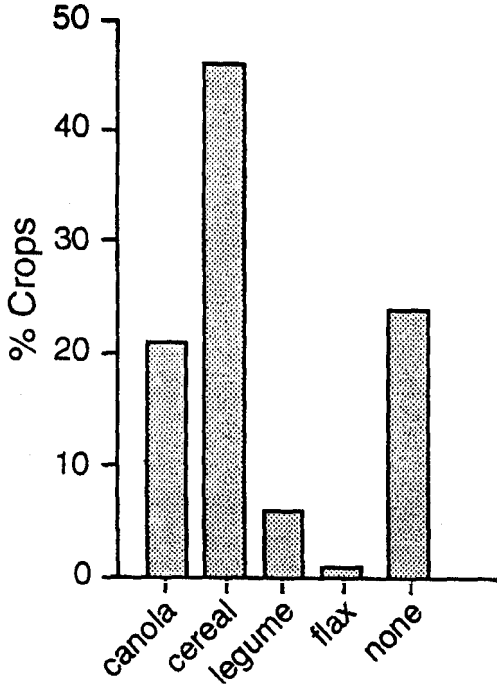

Fig. 1. Proportions of different crops grown in 100 fields in central Saskatchewan, 1977-94.

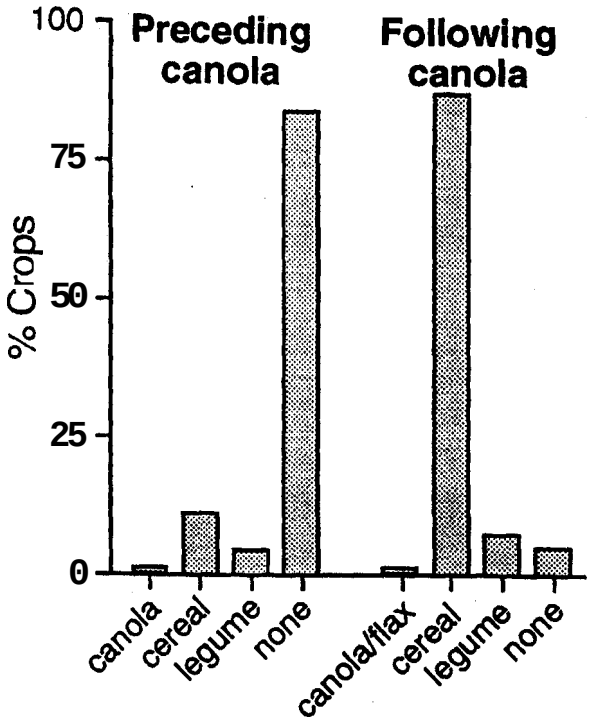

Fig. 2. Proportions of different crops preceding and following rapeseed/canola in rotations in 100 fields in central Saskatchewan, 1977-94.

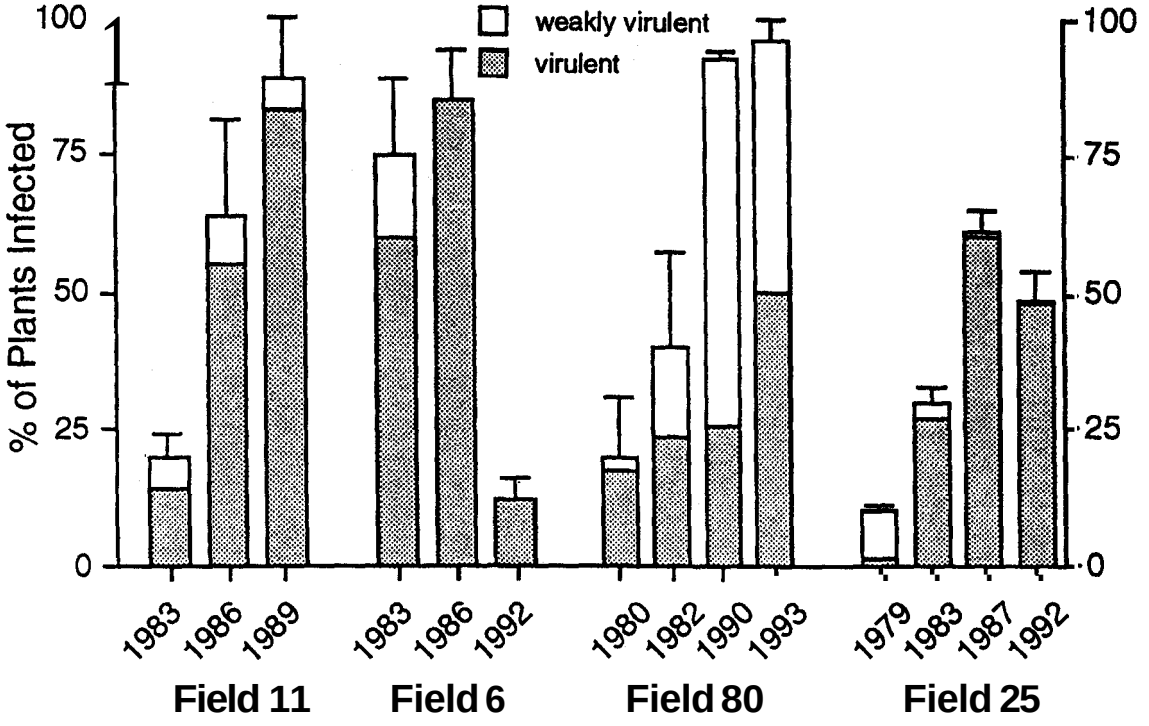

Fig. 3. Changes in incidence of blackleg infection in four Saskatchewan fields and proportions of virulent and weakly virulent strains in succeeding rapeseed/canola crops separated in rotations by from one to seven years.

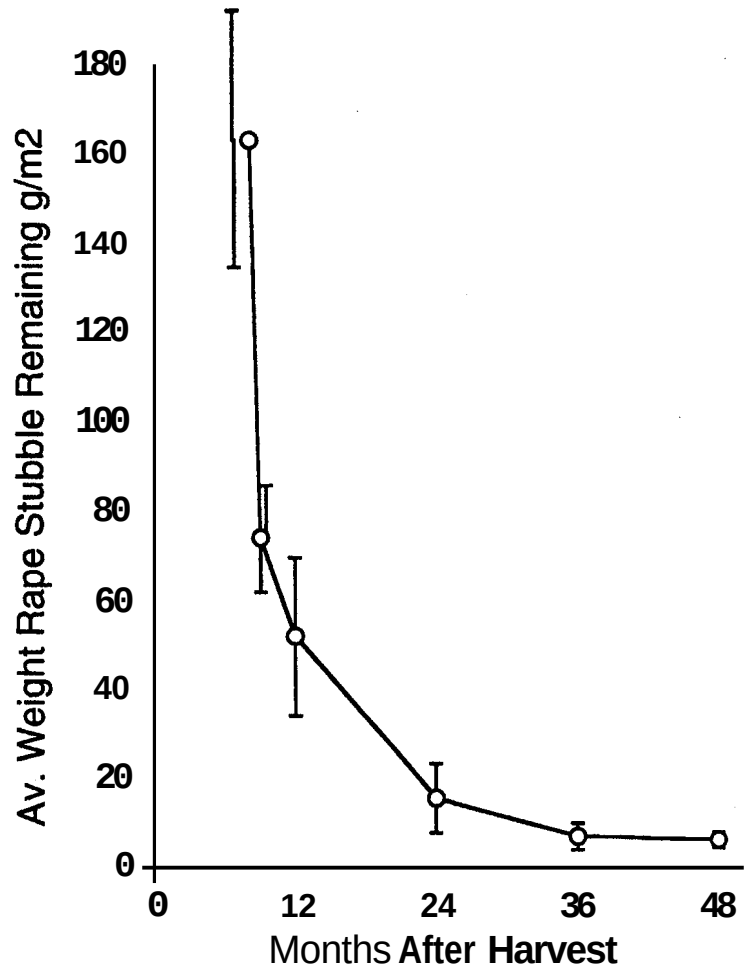

Fig 4. Weight of rape stubble residue remaining/m^2 in field 12 from nine to 48 months after harvest of a 1981 rapeseed crop. Vertical bars represent standard error.