

Effects of Fallow and of Summer and Winter Crops on Survival of Wheat Pathogens in Crop Residues

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ABSTRACT

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Survival of *Fusarium graminearum*, *Cochliobolus sativus*, and *Leptosphaeria nodorum* in wheat, corn, and soybean residues was studied in field plots in southern Brazil during 1988 and 1989. Wheat was harvested in November 1987 and 1988 and was followed by various summer and winter crops or by summer or winter fallow. In 1988, incidence of the three pathogens in the wheat residues was high (70–90%) until April for *C. sativus* and *L. nodorum* and until July or October for *F. graminearum*, then declined progressively. *L. nodorum* had the least ability of the three to survive in wheat residues over time. In both 1988 and 1989, *F. graminearum* and *C. sativus*, but not *L. nodorum*, were detected in wheat residues at the final sampling time (December), about 14 mo after the wheat was harvested. In 1988, the three pathogens survived longer in the wheat residues after summer fallow than after corn or soybean crops, but there was no difference in the incidence of *F. graminearum* and *C. sativus* among winter treatments that followed soybean or corn. In general, the densities of propagules of *C. sativus* and *F. graminearum* in the wheat residues started to decline earlier than their frequency. The three pathogens were also isolated from soybean residues, and *F. graminearum* and *C. sativus* were isolated from corn residues.

Conservation tillage is being increasingly adopted in many parts of the world to control soil erosion, to conserve soil moisture, and for economic reasons. Various conservation tillage practices result in the retention of crop residues on the soil surface that provide a suitable habitat for the establishment, survival, growth, and inoculum production of certain plant pathogens (4,24). Increased inoculum densities or disease severity in conservation tillage systems have been reported for several pathogens of wheat (*Triticum aestivum* L.), including *Leptosphaeria nodorum* Müll. (anamorph *Septoria nodorum* (Berk.) Berk.) (9,10, 25,26), *Cochliobolus sativus* (Ito & Kuribayashi) Drechs. ex Dastur (anamorph *Bipolaris sorokiniana* (Sacc.) Shoemaker) (19), and *Fusarium graminearum* Schwabe (12,13,23).

The importance of crop residues as inoculum sources may depend on several variables, including disease intensity in the preceding host crop, crop sequences, rate of residue decay, competitive sapro-

phytic ability, sporulation potential of the pathogen, and weather variables, particularly precipitation, relative humidity, and temperature. Crop rotations are being investigated in southern Brazil as means to reduce winter fallow, for soil conservation, to improve crop productivity, and for control of plant diseases. Flax (*Linum usitatissimum* L.), canola (*Brassica napus* L.), and legumes are currently being recommended as the best alternatives to the traditional wheat-soybean (*Glycine max* (L.) Merr.) system to control foliar diseases and root rots in wheat (17). However, these alternative crops may differ in their effect on the microclimate of the surface residues and their decomposition, which may in turn affect survival and inoculum production of pathogens. Studies of the fate of wheat pathogens in host residues under different summer and winter crops could provide a basis for forecasting inoculum decline and predicting risks of severe disease in future wheat crops. This would help the development of practical recommendations for controlling pathogenic organisms in conservation tillage cropping systems.

The objective of this study was to examine the relationship of winter and summer fallow and of different winter

and summer crops commonly grown in southern Brazil to survival and inoculum production in crop residues of three wheat pathogens of major economic importance in this region—*F. graminearum*, *C. sativus*, and *L. nodorum*.

MATERIALS AND METHODS

Various sequences of crops were grown under zero tillage in field plots located near Passo Fundo, Rio Grande do Sul, during 1987–1988. Wheat cv. BR 14 was grown in the entire plot area in 1987. The wheat was sown at the recommended rate of 330 seeds per square meter in rows 17–20 cm apart on 6 July and harvested on 1 November. Plots (20 × 15 m) were established in December 1987 and left fallow or planted with corn (*Zea mays* L. 'XL 560') or soybean cv. BR 4. The treatments were replicated four times and arranged in a randomized complete block design. The corn and soybeans were harvested on 29 April, after which the main plots were each subdivided into eight subplots (2.5 × 5 m) in a split-plot design. Wheat cv. BR 14, barley (*Hordeum vulgare* L. 'Antartica 5'), canola cv. CTE, flax cv. Linote, black oat (*Avena strigosa* Schreb.), vetch (*Vicia sativa* L.), and white lupine (*Lupinus albus* L. 'BR 1') were grown in the subplots from May or June to November 1988, or the subplots were left fallow. Data from the barley and lupine treatments of 1987–1988 are not presented. A study with similar crop sequences was done in an adjacent plot area during 1988–1989. In this study, the main plots were 20 × 30 m and the subplots were 5 × 10 m. Fallow was excluded from the summer (December–April) treatments, and barley and lupine were excluded from the winter (June–November) treatments. Fertilizer was applied to plots according to state recommendations (17). Corn was supplied with 10 kg ha⁻¹ of N, 50 kg ha⁻¹ of P, and 50 kg ha⁻¹ of K, applied as 5-25-25, and with 60 kg ha⁻¹ of N as urea, 45 days after planting. Soybean was supplied with 40 kg ha⁻¹ of P and 60 kg ha⁻¹

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of K applied as 0-20-30 at sowing time. The winter crops were each supplied with 10 kg ha⁻¹ of N, 50 kg ha⁻¹ of P, and 50 kg ha⁻¹ of K applied as 5-25-25. Weeds were managed with glyphosate (Nortox) applied prior to planting; diclofop-methyl (Iloxan) was applied to the winter crops, except black oat, in 1989, using recommended rates (17).

Pathogens were recovered at intervals from residues of wheat, corn, and soybean in each plot. During 1987-1988, wheat residues were collected on 8 January, 15 April, and 5 July 1988 from corn, soybean, or fallow plots. At the first two dates, three samples of 100 pieces (about 3 cm long and including a node) of wheat stem residues each were taken from the main plots. On 5 July, three samples of 25 pieces of wheat stem residues each per replicate were collected from the same plots. Stem residues of wheat, corn, and soybean were collected in a similar manner in each of the replicates of the eight subplot treatments on 23 October and 7 December 1988. In the 1988-1989 study, sampling dates were 24 January, 27 April, 6 July, and 25 September 1989; three samples of 25 pieces of residues each were taken from each of the replicate main plots or subplots (25 September only) at each sampling time. Collected residues were washed three times in tap water to remove soil and debris, surface-disinfested by immersion in 0.5% NaOCl for 30 sec and then 70% ethanol for 15 sec, and washed three times in sterile distilled water, as indicated by Fernandez (5).

To estimate incidence of *F. graminearum*, *C. sativus*, and *L. nodorum*, the surface-disinfested pieces of each sample were transferred to potato-dextrose agar amended with 200 mg of streptomycin L⁻¹ and 240 mg of neomycin L⁻¹ or to the selective media of Reis (18) or Mathur and Lee (14). Plates were incubated at 22-24 C for 5-6 days for *F. graminearum* and *L. nodorum* and for 10 days for *C. sativus*. *F. graminearum* was identified by colony morphology, *C. sativus* by conidia, and *L. nodorum* by autofluorescence of colonies under ultraviolet light (14).

Number of propagules of *F. graminearum* and *C. sativus* per gram of residue was estimated by dilution plating as described by Fernandez and Fernandes (6). Residue pieces (3 g per replicate plot for wheat or soybean, 5 g per replicate plot for corn) were incubated on wet filter paper in sealed petri dishes for 7 days. The residues were then vigorously shaken in sterile distilled water for 5 min, and the wash water was plated on the selective medium for *C. sativus* (18) and on Nash-Snyder medium (15) for *F. graminearum*. Colonies were counted after the plates had been incubated for 5-7 days for *F. graminearum* or 10 days for *C. sativus* at 22-24 C. Inoculum density was estimated from the average number of col-

onies on five plates per replicate.

Soil coverage of each of the crops was estimated visually at maturity as the percent ground area of each plot covered by the crop. Dry matter was determined as the weight of 1 m² of the crop cut at soil level at harvest time and left to air-dry in the greenhouse for 5 days.

Weather variables were monitored in a meteorological station located in Passo Fundo 5 km from the experimental plots.

Air temperature (C), rain (mm), and relative humidity (%) were measured daily at 9:00 a.m., 3:00 p.m., and 9:00 p.m. with a thermometer, pluviometer, and psicometer, respectively. Air temperature and relative humidity were taken at 1.5 m above the soil surface.

Number of propagules per gram of tissue and incidence data were subjected to GLM (general linear model) (22), using logarithm and arcsine transforma-

Table 1. Estimated percentage of soil cover and dry matter of winter crops grown after various summer crops in 1988 and 1989

Summer crop	Winter crop	Soil cover (%)		Dry matter (g/m ²)	
		1988	1989	1988	1989
Soybean	Wheat	65 ± 0 ^a	89 ± 3	525 ± 59	905 ± 166
	Black oat	86 ± 3	100 ± 0	708 ± 99	2,013 ± 340
	Canola	61 ± 8	90 ± 4	415 ± 137	1,319 ± 244
	Flax	58 ± 3	78 ± 3	450 ± 49	550 ± 54
	Vetch	95 ± 3	90 ± 4	400 ± 79	1,138 ± 111
Corn	Wheat	66 ± 3	85 ± 4	544 ± 32	681 ± 301
	Black oat	88 ± 10	100 ± 0	758 ± 133	1,838 ± 269
	Canola	39 ± 13	91 ± 3	420 ± 24	863 ± 250
	Flax	49 ± 8	78 ± 6	398 ± 31	488 ± 78
	Vetch	91 ± 9	89 ± 9	471 ± 134	1,175 ± 260
Fallow	Wheat	63 ± 5	NA ^b	465 ± 95	NA
	Black oat	84 ± 9	NA	635 ± 183	NA
	Canola	73 ± 9	NA	313 ± 50	NA
	Flax	55 ± 4	NA	380 ± 50	NA
	Vetch	84 ± 17	NA	381 ± 55	NA

^a Mean value and standard deviation of four replicates.

^b Not applicable.

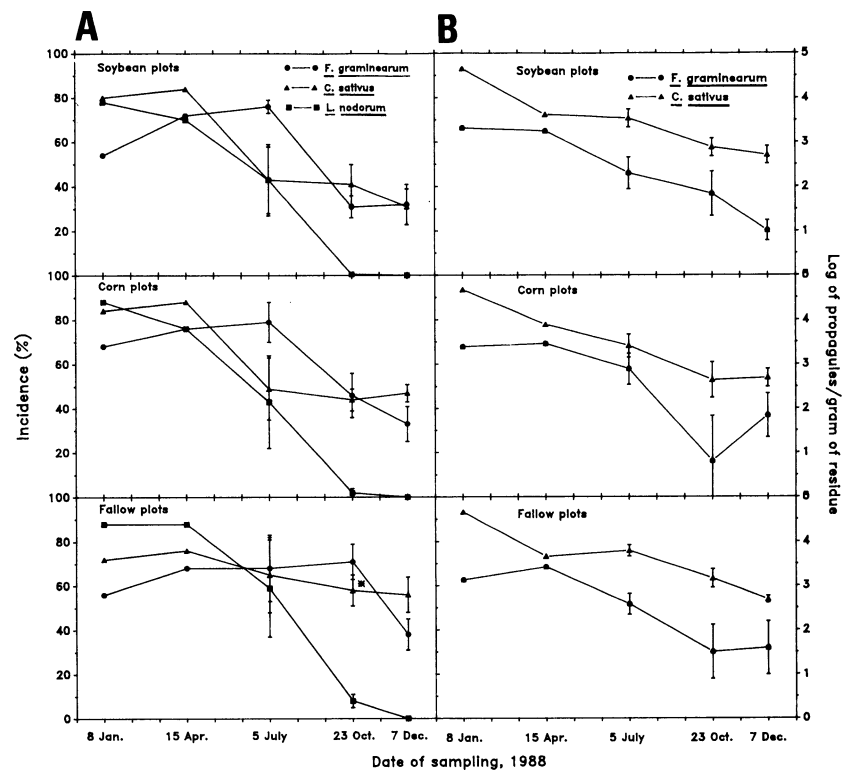


Fig. 1. (A) Percent incidence of *Fusarium graminearum*, *Cochliobolus sativus*, and *Leptosphaeria nodorum* in wheat residues under a crop of soybean, corn, or fallow during the 1987-1988 summer growing season in Brazil. Values for October and December 1988 are averages of percent incidence of six winter treatments; no significant differences ($P > 0.05$) were found except in fallow plots, where an asterisk (*) indicates significant difference according to Duncan's multiple range test ($P \leq 0.05$). (B) Logarithm of the number of propagules of *F. graminearum* and *C. sativus* per gram of residues of wheat under a crop of soybean, corn, or fallow during the 1987-1988 summer growing season. Values for October and December 1988 are means of the number of propagules per gram of wheat residue of all the replicates of the winter treatments. Vertical bars represent standard deviations.

tions, respectively. The interaction of frequency of the pathogens with year, summer and winter treatments, and sampling times and the interaction of inoculum density with sampling times were analyzed. When *F* values were significant at $P = 0.05$, treatment means were compared using Duncan's multiple range test.

RESULTS

Canopy density. Soil cover of all winter crops except vetch was greater in 1989 than in 1988, and it was greater for black oat and vetch than for other crops in 1988 (Table 1). Dry matter of crops was in most cases also higher in 1989 than in 1988, and it was higher for black oat than for other crops (Table 1). In 1989,

flax had the lowest soil cover and dry matter of all winter crops.

Survival of pathogens in wheat residues. *F. graminearum*, *C. sativus*, and *L. nodorum* were detected in wheat residues that had been left on the soil surface after harvest in November 1987 and 1988. Incidence of all three pathogens in wheat residues collected in January averaged 74% in the 1987–1988 study (Fig. 1A) and 57% in the 1988–1989 study (Fig. 2A). Thereafter, patterns of incidence of the pathogens in the wheat residues was largely a function of the pathogens as opposed to the summer crop sequences or use of fallow.

In the 1987–1988 study, incidence patterns of the pathogens after April, aver-

aged across the winter crops from October on, differed markedly (Fig. 1A). On 5 July, *F. graminearum* was present at high levels in all of the summer treatments (average of 74%) but had declined significantly by 23 October ($P \leq 0.05$) except in plots kept fallow the preceding summer, where the incidence did not decline significantly ($P < 0.05$) until December. In addition, the incidence of this fungus tended to increase before starting to decline. The incidence of *C. sativus* declined markedly between 15 April and 5 July in the soybean and corn treatments but not significantly ($P > 0.05$) between 5 July and 7 December in any of the three summer treatments. On 7 December, the last sampling date, incidence of *F. graminearum* and *C. sativus* in the wheat residues of all summer treatments averaged 41 and 45%, respectively. The incidence of *L. nodorum* declined sharply after 15 April and from 5 July to 23 October ($P \leq 0.05$) in all treatments. In none of the three summer treatments was this fungus detected by 7 December 1988.

In the 1988–1989 study, incidence of *C. sativus* in the wheat residues of the soybean plots did not change significantly ($P > 0.05$) from January to the final sampling date in September. For the corn treatment, incidence of *C. sativus* in wheat residues was significantly lower ($P \leq 0.05$) in September than in January. *F. graminearum* was less frequent ($P \leq 0.05$) on 25 September than on 27 April or 6 July for the soybean and corn treatments, respectively (Fig. 2A). Incidence of *L. nodorum* in wheat residues, however, declined significantly ($P \leq 0.05$) from January on. This pathogen was not detected in residues on 6 July in plots where corn had been grown in the summer or on 25 September in plots where soybeans were produced. Both *F. graminearum* and *L. nodorum* were less frequent ($P \leq 0.05$) in 1989 than in 1988.

There were no significant differences ($P > 0.05$) in the incidence of all three pathogens in wheat residues among summer treatments in 1989, but significant differences were observed in October and December of 1988. In October 1988, the frequency of *L. nodorum* was significantly greater ($P \leq 0.05$) in plots that had been fallow in summer than in plots planted with soybean or corn. *F. graminearum* and *C. sativus* were also more frequent ($P \leq 0.05$) in the summer fallow treatment than in the other summer treatments in October 1988, and levels of *C. sativus* were higher ($P \leq 0.05$) in both the fallow and the corn treatments than in the soybean treatment in December. No significant differences ($P > 0.05$) were found in the incidence of *C. sativus* or *F. graminearum* in wheat residues among the six winter treatments that followed summer crops of soybean or corn in 1988 or 1989. In the summer fall-

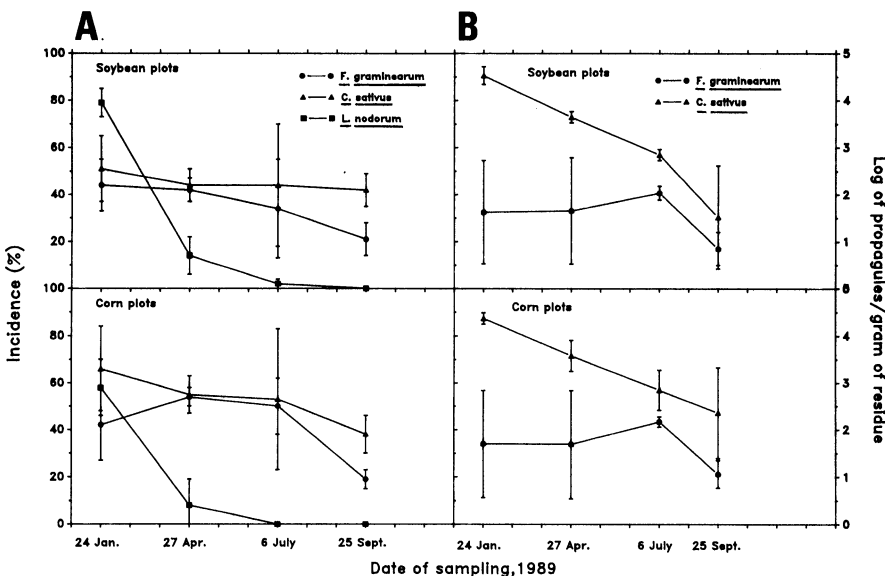


Fig. 2. (A) Percent incidence of *Fusarium graminearum*, *Cochliobolus sativus*, and *Leptosphaeria nodorum* in wheat residues under a crop of soybean and corn during the 1988–1989 summer growing season in Brazil. Values for September 1989 are averages of the mean incidence of each of the six winter treatments; no significant differences ($P > 0.05$) were found. (B) Logarithm of the number of propagules of *F. graminearum* and *C. sativus* per gram of residue of wheat under a crop of soybean or corn during the 1988–1989 summer growing season. Values for September 1989 are averages of the mean incidence of each of the four replicates. Vertical bars represent standard deviations.

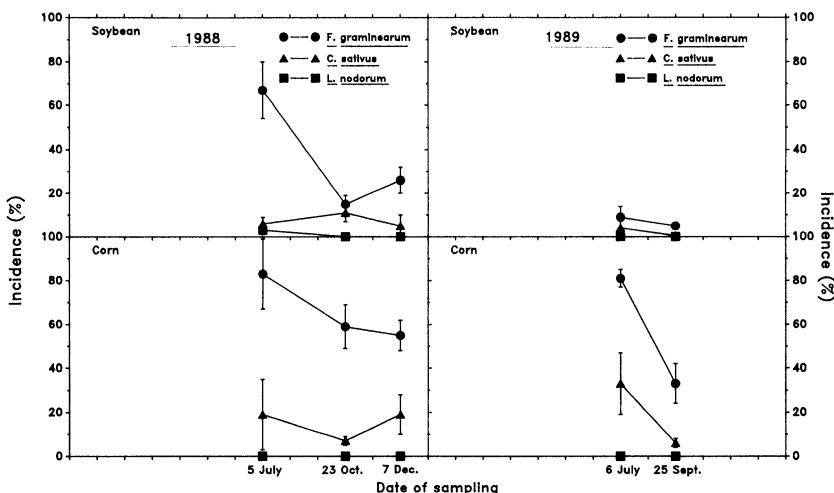


Fig. 3. Percent incidence of *Fusarium graminearum*, *Cochliobolus sativus*, and *Leptosphaeria nodorum* in soybean and corn residues during the winter growing season of (A) 1988 and (B) 1989 in Brazil. Values for October and December 1988 and September 1989 are averages of the mean incidence of each of the six winter treatments. Vertical bars represent standard deviations.

low treatment, a significant difference in the incidence of *C. sativus* among winter treatments was observed in October 1988; incidences were 10–24% greater in the winter fallow and wheat treatments than in the canola, flax, and black oat treatments but did not differ from those in vetch (*data not presented*). The values shown in Figures 1A and 2A for October and December 1988 and September 1989 are averages of the mean incidence of each of the six winter treatments.

Densities of *F. graminearum* and *C. sativus* in wheat residues. Number of propagules of the pathogens per gram of tissue declined significantly ($P \leq 0.05$) throughout the experimental period in both 1988 and 1989, except for *F. graminearum* in 1989 (Figs. 1B and 2B). In some instances, difficulties were encountered toward the end of the experimental periods in finding sufficient nodal tissue for this analysis or with the techniques used. In some instances, several *Fusarium* spp. overran the plates, and colonies of *F. graminearum* could not be detected. Therefore, comparisons of propagule densities in residues of the various winter treatments were not possible. The mean number of propagules per gram of tissue for each of the replicates was calculated on the basis of all winter treatments where this could be determined. The values for October and December 1988 and September 1989 shown in Figures 1B and 2B are averages of the mean number of propagules of each of the four replicates.

In both the 1987–1988 and 1988–1989 studies, the number of propagules of *C. sativus* per gram of wheat residue started to decline from January on. There was a significant ($P \leq 0.05$) decline until October 1988 and April or July 1989 in the corn and soybean treatments. This decline continued ($P \leq 0.05$) to December in the fallow plots of 1988. The number of propagules of *F. graminearum* did not begin to decline until after April 1988, and a significant ($P \leq 0.05$) decline was observed by October in the corn and the fallow treatments and by December in the soybean treatment (Figs. 1B and 2B). In most cases, the decline in the number of propagules per gram of tissue for both fungi occurred earlier than the decline in their actual incidence (Figs. 1A and 2A).

Survival of pathogens in soybean and corn residues. All three pathogens were recovered from soybean residues, and *F. graminearum* and *C. sativus* were found in corn residues in both 1988 and 1989 (Fig. 3). Incidence of the fungi in soybean residues was lower in 1989 than in 1988. Incidence of *C. sativus* generally was lower than that of *F. graminearum* in both types of residue, and incidence of *F. graminearum* decreased significantly ($P \leq 0.05$) from July to October 1988 in corn and soybean and from July to September 1989 in corn residues. Incidence of *C. sativus* declined significantly

($P \leq 0.05$) in both summer crops from July to September 1989 but did not change ($P > 0.05$) throughout time in 1988.

No significant difference ($P > 0.05$) in the survival of fungi in soybean or corn residues was found among the winter treatments in 1988 or 1989. Values in Figure 3 represent averages of the mean incidence of the fungi in each of the six winter treatments.

Weather variables. Monthly means for temperature and relative humidity in 1987, 1988, and 1989 did not differ markedly from the long-term (1950–1979) average values (Fig. 4). For all 3 yr, however, the distribution of rain throughout the year differed from the long-term means. January and September were the

months with greatest precipitation in 1988 and 1989. Total precipitation during the winter (June–October) of 1989 was also higher than during the same period the two previous years.

DISCUSSION

F. graminearum, *C. sativus*, and *L. nodorum* were isolated from residues of wheat and of the summer crops corn and soybean. Of these fungi, only *F. graminearum* is a pathogen of corn. All three fungi have been reported to survive in soybean residues (6).

The findings of this study indicated that sporulation potential, but not percent incidence, of *C. sativus* in wheat residues declined appreciably in the summer (January–April). Incidence of this

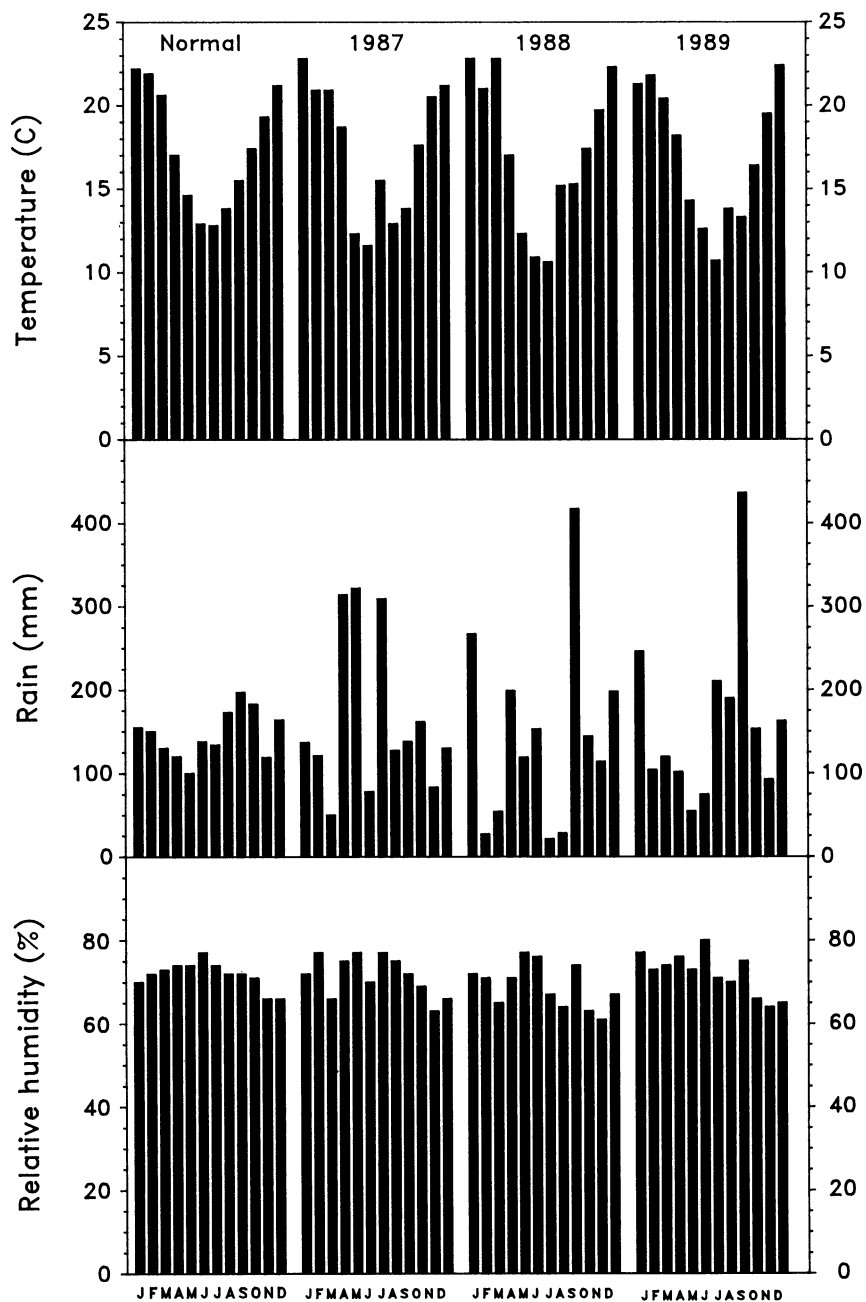


Fig. 4. Average monthly temperature, rainfall, and relative humidity for 1987, 1988, and 1989 taken at the meteorological station at Passo Fundo, Rio Grande do Sul, Brazil. Normal values represent the average for 1950–1979.

pathogen began to decline only after the summer crops were harvested, and the decline in 1988 was faster after corn and soybean than after fallow. This indicated that pathogen incidence was affected by residues of the summer crops on the ground after harvest, as opposed to canopies or other aspects of the crops during the growing season. The summer residues possibly kept the wheat residues moist for long periods and may have promoted a high level of microbial activity in the decomposing straw that was suppressive of or competitive with growth of *C. sativus*. A further possibility was that antimicrobial substances leached from the summer residues in their initial stages of decomposition and suppressed *C. sativus*.

Decline in the sporulation potential of *C. sativus* in wheat residues during the summer likely related to initial decomposition of the residues. A rapid decay of residues has been reported during the first few weeks after harvest (2,8,16,20) and was associated with leaching and decomposition of easily available organic compounds (1,2). Intense leaching of surface straw often occurs with each rainfall event (3). Precipitation in this area was well above normal in January of both years, and average temperatures during the summer were above 20 C (Fig. 4). High temperatures and abundant precipitation may have favored a decrease in the available nutrients and/or may have promoted growth and sporulation of fungi on straw, thus exhausting the substrate and decreasing the area colonized by the fungi. The increased microbial activity might also have reduced the ability of *C. sativus* to grow and multiply.

The effect of initial residue decomposition was less apparent on *F. graminearum* than on *C. sativus*, since its sporulation density declined later than that of *C. sativus*, reflecting the higher competitive saprophytic ability of *F. graminearum* (5).

Differences in the persistence of the three fungi in straw over time, particularly in 1988, also appeared to reflect differences in their competitive saprophytic ability, suggesting a decrease in that ability from *F. graminearum* to *C. sativus* to *L. nodorum*. In addition, the tendency of *F. graminearum* to increase in incidence during the first few months after harvest reflected a greater ability of the pathogen not only to survive in colonized residues but to colonize other residues, an ability not evident in the other pathogens. Summerell and Burgess (23) also reported an increase in recovery of *F. graminearum* from wheat straw, which was eventually followed by a decline in its frequency.

Some of the observed differences between years in the survival of the three pathogens seemed to be correlated with environmental variables. Weather factors probably contributed to the differ-

ences in survival and sporulation potential observed in the 2 yr of observations. The higher precipitation in November–March of 1988–1989 (778 mm) than in the corresponding period of 1987–1988 (559 mm) may have contributed to the lower initial levels of *F. graminearum* and *C. sativus* in wheat residues and the faster decline in sporulation density of *L. nodorum* in 1989 than in 1988. Similarly, the 64% greater rainfall measured during May–August in 1989 than in 1988 may be responsible for the lower incidence of *F. graminearum* in corn and soybean residues in 1989 than in 1988.

Although there were marked differences in canopy density among the winter crops, as estimated on the basis of coverage of the soil by the canopies and crop dry matter, survival of the three pathogens in wheat residues on the soil did not differ significantly among winter treatments at the final time of sampling. In addition, monitoring of straw decomposition throughout 1989 also showed no difference in decomposition of wheat straw among the different winter treatments (*data not presented*). Although winter crops with high canopy densities would be expected to accelerate residue decomposition and pathogen decline by prolonging residue moisture over that in crops with sparser canopies or in fallow, they might also be drawing up more moisture from the soil, thus compensating for the increase in moisture retention in the upper layers of residues. This could lead to the creation of droughty conditions that could retard the overall rate of straw decomposition (1,7,11,21). Whether this holds true in southern Brazil, where moisture generally is not a limiting factor during the growing season, is not known. Nevertheless, similar results were obtained in 1988 and 1989 despite differences in the amount and distribution of precipitation and crop growth in the winter between those years (Fig. 4 and Table 1).

We can conclude that there is a complex interaction among factors affecting fungal pathogens colonizing crop residues. Monitoring of the residue and soil microclimate under different crops throughout the year, and how these relate to residue decomposition and the soil and residue biological community, would help elucidate the nature of the interactions occurring on the soil surface and how they affect pathogen populations and disease development in subsequent crops. Such information would be of value in any effort to suppress pathogen populations in conservation tillage systems.

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