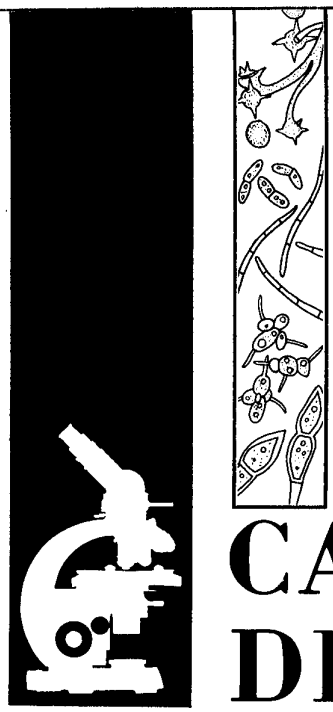
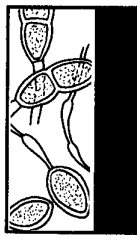
VOL. 53, No. 3, SEPTEMBER, 1973



CANADIAN PLANT DISEASE SURVEY



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CANADIAN PLANT DISEASE SURVEY

RESEARCH BRANCH CANADA DEPARTMENT OF AGRICULTURE

CONTENTS

"The Canadian Plant Disease Survey is a periodical of information and record on the occurrence and severity of plant diseases in Canada. It will also accept other original information such as the development of methods of investigation and control, including the evaluation of new materials. Review papers and compilations of practical value to phytopathologists will be included from time to time."

WHEAT LOSSES DUE TO COMMON ROOT ROT IN THE PRAIRIE PROVINCES OF CANADA, 1969-71[1]

R.J. Ledingham[2], T.G. Atkinson[3], J.S. Horricks[3], J.T. Mills[4], L.J. Piening[5], and R.D. Tinline[2]

Abstract

A survey was conducted, 1969-71, to estimate losses due to common root rot of wheat on the Canadian Prairies. The estimated average annual loss over the entire area for the 3 years was 5.7% or 30 million bushels. Diseased plants suffered a reduction in number of heads per plant, in kernel weight, and in size of heads as compared to healthy plants. Protein content of the grain was little affected by root rot. A formula is presented for conversion of percentage diseased plants in a field to loss in yield.

Introduction

The last comprehensive survey to estimate losses due to common root rot in wheat caused by Cochliobolus sativus (Ito & Kurib.) Drechsl. ex Dastur, condial state Helminthosporium sativum Pamm., King & Bakke., syn. Bipolaris sorokiniana (Sacc. in Sorok.) Shoem., and by Fusarium spp., on the Canadian Prairies was carried out in 1939-41 by Machacek (10). This study showed losses of 8, 16, and 12% respectively for the 3 years. Since then, there has been a considerable change-over in varieties used and a radical change in cultural procedures; competition by broad-leaved weeds has been largely eliminated through the use of herbicides and the land has been under cultivation an additional 30 years.

Wheat and barley are the important crops subject to common root rot. They so dominate prairie agriculture that rotations that free the land from one or other of these crops for more than a year or two at a time are not practical. Thus wheat seldom is planted on land with an inoculum potential low enough to significantly limit disease development (8). Cultural procedures have shifted to almost universal adoption of surface tillage implements in contrast to the widespread use of the mold-board plow at the time of Machacek's survey (10). Consequently, more of the inoculum of the causal organisms is retained near the soil surface. Retention of crop debris on the soil surface perhaps allows spore production from infected tissues over a longer period than was the case when the plow was used. Furthermore, conidia probably survive longer on or near the soil surface than they do when buried in the soil (9). Nevertheless, "old" fields do not appear to be problem fields as far as common root rot is concerned and spore population or inoculum potential is not the sole consideration in manifestation of the disease.

Creelman (3), LeClerg (7) and McDonald et al. (12, 13) and others have adequately outlined the purpose and detailed the desirability of estimates of losses from crop diseases. This report presents the results of a cooperative survey covering Alberta, Manitoba, and Saskatchewan for the crop years 1969-70-71, designed to estimate the yield reductions in wheat attributable to common root rot.

Materials and methods

Survey routes in each province were chosen at the discretion of the cooperating individuals and were such as to cover most Crop Districts (CD) in Manitoba and Saskatchewan and Agricultural Reporting Areas (ARA) in Alberta. Fields were chosen at random, except as noted below, along the survey routes. Time, weather, and resources occasioned some curtailment of plans or omissions of crop districts. The surveys were conducted during the short period when the wheat crop was ripening and only fields in the firm dough stage were sampled. Shallowly planted fields with many plants lacking a subcrown internode were rejected. Field margins were avoided.

In 1969 and 1970 each field was sampled by selecting two 1-yd^2 quadrats 15-20 yards

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apart. All the plants from each quadrat were pulled carefully, bagged, labelled, and transported to headquarters for processing.

In 1971 a single diagonal traverse of 100 paces was made in each field, starting 25 paces from the field margin. A small handful of about 8 to 10 plants was pulled at 4-pace intervals along the traverse, giving a sample of over 200 plants.

In the laboratory each plant within a sample was assigned to one of four disease classes, clean, slight, moderate, and severe (Figure 1), based on extent and severity of lesions on the subcrown internode. Plants lacking an appreciable length of subcrown internode on which an assessment could be made were placed in a fifth group, unclassified. For each class the number of plants and heads and the weight of grain were recorded. The data from the two quadrats in each field, taken in 1969 and 1970, were bulked. In Alberta in 1969 and 1970, paired samples were taken from 45 and 56 fields respectively, and in 1971 single samples were taken from 55 fields. In Manitoba paired samples were taken from 25 and 20 fields in the first 2 years and single samples from 29 fields in 1971. In Saskatchewan in 1969 and 1970 paired samples were obtained from 53 and 71 fields respectively and in 1971 single samples were taken from 155 fields. In 1969 and 1970, the samples averaged 175 plants per quadrat or 350 per field while in 1971, the average was 275 plants per field.

Protein content was determined on grain from the clean and severely diseased classes of 25 fields in 1970. Thousand kernel weights were taken on some of the material each year. In 1969 and 1970, the heads of all samples in Saskatchewan were examined in an effort to identify the variety.

Losses for each field were calculated using the formula derived by Machacek (10):

$$\text{Percent loss in yield} = 100 - \left(\frac{W}{W_1 \times N} \times 100\right),$$

where W is the total weight of grain from a sample, and W_1 the average weight of grain per plant from the clean plants of the sample, and N the total number of plants in the sample. In other words, the percent loss is the difference between 100 and the actual yield expressed as a percentage of the potential yield.

The percent loss in yield for a CD or ARA was expressed as the mean of the percent losses for the fields samples in the specified area. This mean was applied to the actual production statistics (1, 4, 11) for the area to calculate potential production. In Alberta and Manitoba where all CD's or ARA's were not sampled, the mean for those areas sampled was applied to the ones not sampled to derive potential production. Potential production for the provinces and the entire region was obtained by summation of the values for the CD's or ARA's. Loss in bushels and percentage loss were calculated from the difference between potential and actual production.

The soil zones were superimposed on a crop district map of the prairie provinces (Figures 2-4). Zone 1, in the southern part of Alberta and Saskatchewan, comprises the brown soil area of the prairies. It is characterized by high evaporation; however, it has extensive areas well suited to cereal production. Zone 2 roughly parallels Zone 1 on the north. The soil is dark brown and moisture conditions are somewhat more favorable than in Zone 1. In it are many areas of medium and heavy clay soils. Zone 3 is the black soil zone comprising most of the cultivated land in Manitoba and in general the parkland portion of Saskatchewan and Alberta. Moisture conditions are usually favorable. Zone 4 occupies the area between the parkland and boreal forest. Soils are degraded black and gray and moisture is generally good. The average percentage loss for all fields sampled within each soil zone was calculated to give soil zone losses.

While the survey was confined to hard red spring wheat, the results were projected to include durum wheats as well; a breakdown in production between durum and hard red wheats is difficult to obtain. Further, observations and field experiments indicate that the durum wheats are somewhat more susceptible to common root rot than most of the recommended varieties of common wheat. Thus the data presented are for all wheats in the three provinces.

Results

The locations of the fields sampled in each province during the 3 years of the survey are shown in Figures 2 to 4. The soil zones also are outlined on the maps (Figures 2 to 4) and the average loss within each soil zone in each of the 3 years is shown. For example, the average losses for soil zones 1 to 4 in 1971 were 4.6%, 3.8%, 5.2%, and 4.8% respectively (Figure 4).

Percentage loss by CD or ARA for the three provinces for the 3 years is given in Table 1. In Table 2, acreage, yield, total production, percent loss, potential production, loss in bushels, and number of fields involved in the survey are summarized by province and year. The percent losses in 1969, 1970, and 1971 were as follows: 4.4%, 6.3%, and 5.5% respectively in Alberta, 6.2%, -3.8%, and 5.7% in Manitoba and 5.7%, 10.2%, and 4.0% in Saskatchewan.

In Table 3 are shown the average losses in yield of each disease class and the unclassified group (plants lacking a subcrown internode), relative to the clean class, for the three provinces in each of the 3 years. The mean reduction for the three provinces

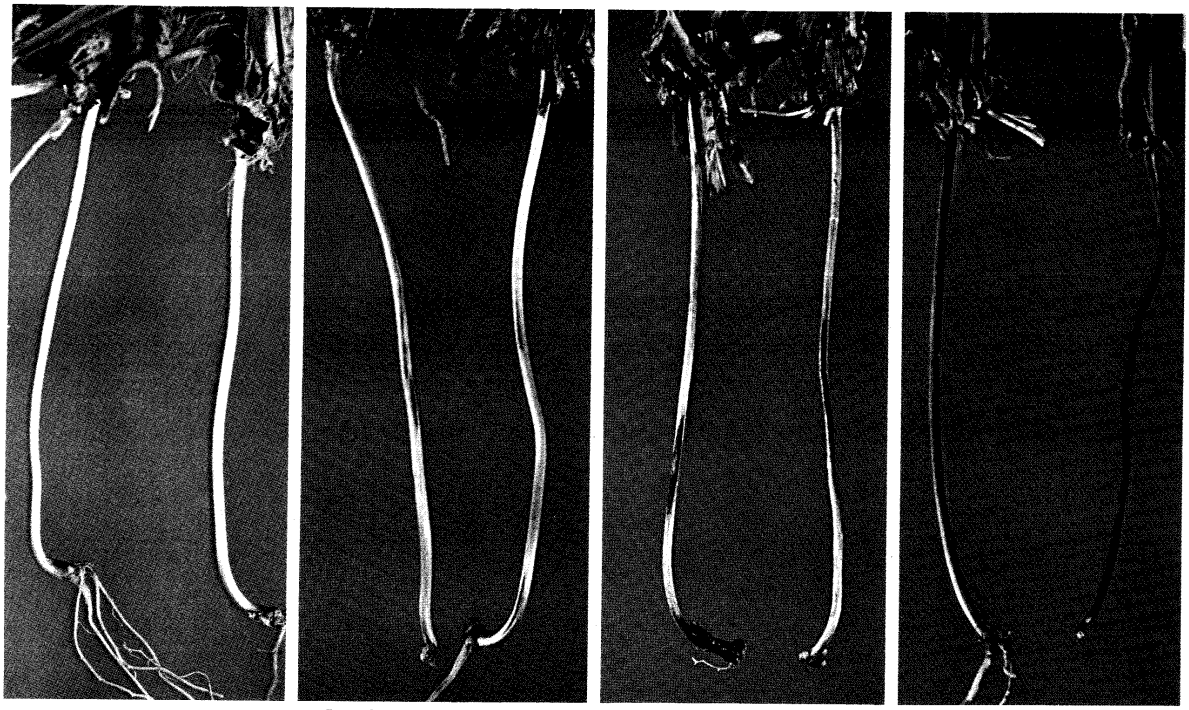

Figure 1. Symptoms of common root rot on subcrown internodes of mature wheat plants; left to right, severity classes clean, slight, moderate, and severe.

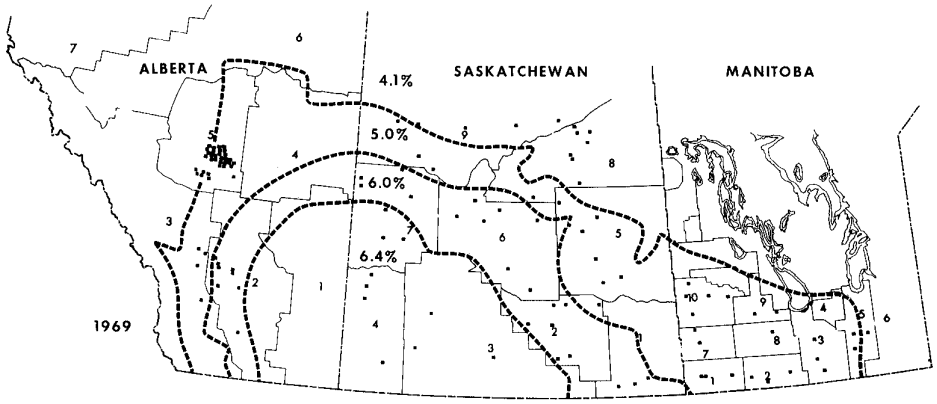

FIG. 2

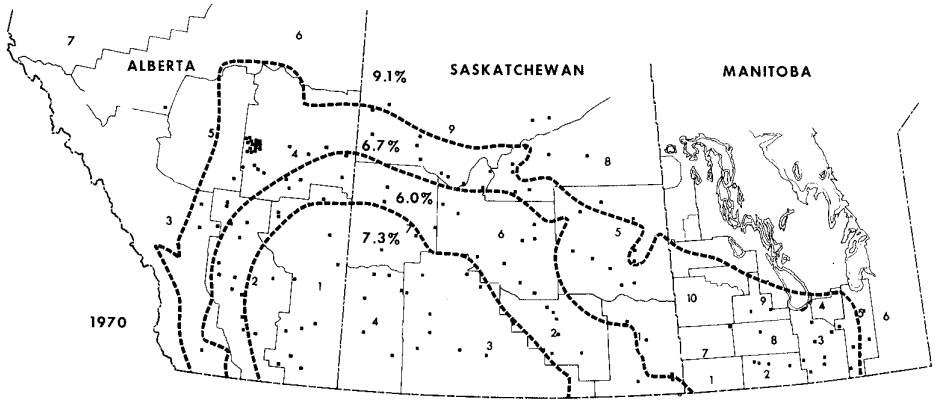

FIG. 3

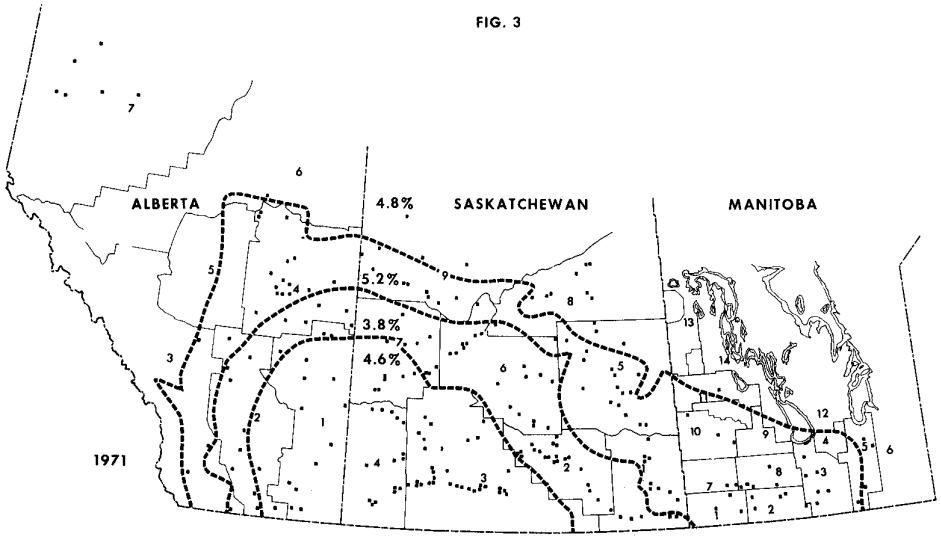

FIG. 4

Figures 2-4. Location of wheat fields sampled in each of the prairie provinces in 1969, 1970, and 1971. Numbered zones refer to crop districts (in Alberta, agricultural reporting areas); heavy broken lines outline the four major soil zones, and percentages indicate the average loss from common root rot in each soil zone.

Table 1. Percent losses from root rot in wheat by Crop Districts or Agricultural Reporting Areas in the prairie provinces, 1969-71

	Saskatchewan			Manitoba			Alberta		
Year	CD	No. of fields	Loss (%)	CD	No. of fields	Loss (%)	ARA	No. of fields	Loss (%)
1969	1	3	5.5	1	3	8.9	2	8	7.2
	2	7	3.8	2	2	-2.3	3	4	-3.2
	3	3	4.8	3	7	5.8	5	33	3.5
	4	4	10.4	5	3	3.3			
	5	7	7.2	7	2	3.7			
	6	8	5.4	8	1	6.5			
	7	7	6.7	9	2	28.3			
	8	6	5.3	10	5	0.3			
	9	8	6.3						
	Mean		6.2			5.2			2.5
1970	1	5	14.6	2	3	-6.3	1	11	3.7
	2	7	7.4	3	8	3.2	2	15	5.4
	3	9	8.6	5	5	-0.2	3	4	5.1
	4	6	10.5	7	1	-12.8	4	24	7.6
	5	10	8.5	8	1	-6.6	5	1	16.9
	6	14	8.7	9	2	-6.5	6	1	2.2
	7	5	6.2						
	8	5	15.9						
	9	10	9.1						
	Mean		9.9			-4.8			6.8
1971	1	13	4.1	1	3	9.6	1	14	3.5
	2	22	3.9	2	5	5.6	2	11	5.7
	3	33	4.4	3	6	3.5	3	4	2.8
	4	15	6.8	5	4	5.1	4	19	8.0
	5	18	3.2	7	3	3.1	6	1	8.1
	6	20	3.4	8	4	4.9	7	6	2.5
	7	13	3.2	10	4	8.8			
	8	9	2.9						
	9	12	5.7						
	Mean		4.2			5.7			5.1

over 3 years was 6.0% for the slight disease category and 12.5% and 28.2% for the moderate and severe categories respectively. The unclassified plants on the average yielded slightly more grain than the clean category. This was particularly true in Saskatchewan, where the increase over the 3 years was 12%.

The average numbers of heads per plant for the disease classes and the unclassified category for the three provinces in each of the 3 years are shown in Table 4. It will be seen that the slight disease class suffered a reduction in heads of 3.7%, the moderate class 8.3%, and the severe class 15.2%. In Saskatchewan head numbers per plant in the unclassified category were appreciably higher than in the clean class each year; the mean 3-year average was 11.3% higher. In Alberta and Manitoba no appreciable differences were observed.

Thousand kernel weights from some representative samples taken in each of the 3 years are shown in Table 5. Kernel weights in the severe class averaged 6.7% lower than those in the clean class.

Table 2. Wheat losses in Alberta, Manitoba, and Saskatchewan due to common root rot 1969, 1970, 1971

Province and year		Acreage ('000)	Yield (bu/ac)	Production ('000 bu)	% Loss	Potential production ('000 bu)	Loss ('000 bu)	No. of fields sampled
Alta.	1969	5,300	26.4	140,000	4.4	146,400	6,400	45
	1970	2,600	27.7	72,000	6.3	76,800	4,800	56
	1971	3,500	26.3	92,000	5.5	97,300	5,500	55
Man.	1969	2,500	25.6	64,000	6.2	67,500	4,000	25
	1970	1,400	21.8	30,500	-3.8			20
	1971	2,400	29.2	70,000	5.7	74,200	4,200	29
Sask.	1969	16,600	27.8	461,000	5.7	488,600	27,600	53
	1970	8,000	26.2	210,000	10.2	233,800	23,800	71
	1971	12,800	26.7	342,000	4.0	356,200	14,200	155

Table 3. Percent loss in yield of wheat in root rot classes derived from a comparison of yields from clean and diseased plants

Province and year		Slight	Moderate	Severe	Unclassified
Alta.	1969	1.5	4.9	11.5	-6.9
	1970	7.7	4.9	27.5	2.0
	1971	6.7	10.9	25.2	-0.7
Mean		5.3	6.9	21.4	-1.8
Man.	1969	7.1	10.4	22.4	4.8
	1970	-5.8	19.6	46.8	-7.5
	1971	7.7	17.6	27.1	11.4
Mean		3.0	15.8	32.1	2.9
Sask.	1969	9.6	11.3	28.0	-9.9
	1970	12.7	19.6	39.2	-12.0
	1971	6.7	13.4	26.5	-14.2
Mean		9.6	14.7	31.2	-12.0
Grand mean		6.0	12.5	28.2	-3.7

Table 4. Average number of heads per wheat plant in different root rot disease classes from Alberta, Manitoba, and Saskatchewan, 1969-71

Province and year		Clean	Slight	Moderate	Severe	Unclassified
Alta.	1969	2.1	2.0	2.0	1.9	2.0
	1970	2.2	2.0	2.0	1.8	2.2
	1971	2.1	2.0	1.9	1.8	2.1
Mean		2.13	2.00	1.97	1.83	2.10
Man.	1969	1.9	1.8	1.7	1.7	1.8
	1970	1.6	1.8	1.5	1.2	1.8
	1971	1.7	1.7	1.6	1.7	1.6
Mean		1.73	1.76	1.60	1.53	1.73
Sask.	1969	1.9	1.8	1.8	1.6	2.1
	1970	2.2	2.0	1.9	1.6	2.4
	1971	2.0	1.9	1.8	1.7	2.2
Mean		2.03	1.90	1.83	1.63	2.26
Grand mean in %		100	96.3	91.7	84.8	

The protein levels of grain from clean and severely diseased samples did not differ much; clean samples averaged 12.25% protein and severely diseased samples 12.47%.

Virtually all of the Saskatchewan fields sampled in 1969-70 proved to be Thatcher or the Thatcher derivatives Canthatch and Manitou, except for a few of the solid stemmed Rescue type. Therefore a comparison of varietal root rot losses was not feasible.

Table 5. Thousand kernel weights of wheat from representative clean and severe root rot classes in Alberta and Saskatchewan

Year	Province	No. of samples	Clean (g)	Severe (g)	% Shrinkage
1969	Alberta	24	27.55	26.13	5.16
1970	Saskatchewan	25	26.20	24.76	5.50
1971	Alberta	7	28.74	25.36	11.76
1971	Saskatchewan	50	30.20	28.85	4.47
	Mean		28.17	26.27	6.7

Relation of disease rating to yield loss

Some years ago Sallans (1964, unpublished) introduced a simplified method into the root rot survey in Saskatchewan. Instead of separating the plants into four classes, clean, slight, moderate, and severe, he combined the clean and slight, and the moderate and severe into two classes, healthy and diseased respectively. In field practice the percentage of diseased plants in a sample is the disease rating.

In the 4-class system, giving weights of 2, 5, and 10 for the slight, moderate, and severe disease categories, the disease rating Y is derived, on a 100 plant sample, from the formula

$$Y = \frac{2a + 5b + 10c}{10}$$

where a, b, and c are respectively the number of slightly, moderately, and severely diseased plants in the sample. The weights assigned, namely 2, 5, and 10 are roughly proportional to the losses suffered by the slight, moderate, and severe classes, namely 6.0, 12.5, and 28.2 (Table 3). The Saskatchewan samples for the years 1969-71, a total of 270, when assessed by the 2-class and the 4-class method of rating gave mean disease ratings of 18.88 and 18.83 respectively. The coefficient of correlation between ratings for the two methods was 0.985.

Disease ratings calculated in this way do not reflect yield loss directly, nor are they intended to do so. The disease rating must be multiplied by a conversion factor to give an approximation of loss. In earlier studies Sallans (unpublished) derived the factor 0.4 and found this to be realistic. The factor is simply obtained by dividing the calculated percentage loss in a field or group of fields by the observed disease ratings for these fields. In Table 6 the conversion factors for each crop district in Saskatchewan for the 3 years of the study are given to indicate the degree of variability that occurred among years and districts.

Table 6. Conversion factors and the number of fields involved in determination of each factor for the years 1969-71 in Saskatchewan

	Conversion factor			No. of fields		
CD	1969	1970	1971	1969	1970	1971
1	0.41	0.50	0.23	3	5	13
2	0.38	0.30	0.33	7	7	22
3	0.22	0.36	0.21	3	9	33
4	0.29	0.43	0.23	4	6	15
5	0.31	0.33	0.26	7	10	18
6	0.25	0.53	0.33	8	14	20
7	0.29	0.38	0.24	7	5	13
8	0.30	0.70	0.19	6	5	9
9	0.27	0.49	0.39	8	10	12
Mean	0.30	0.45	0.27			

Discussion

The 3 years of the study were characterized by better than normal wheat crops in all provinces, reflecting near-adequate moisture. The mean yields for the 3 years were 26.8, 25.5, and 26.9 bu/ac in Alberta, Manitoba and Saskatchewan (15) respectively, compared with a 1940-1969 average of 20.8, 22.0, and 18.5 bu/ac for the three provinces (5,6). It is recognized that common root rot is aggravated by drought, hence one would expect higher losses in dry years.

The sampling was considered minimal; however, in view of the vast area to be surveyed and the time involved in processing a sample, the input was considerable. In Manitoba and Saskatchewan, one person in each province sorted the plants into their disease classes while in Alberta, three workers were responsible. The multiplicity of observers was not considered a serious weakness. Although different people may set slightly different standards, there is not much room for difference in deciding that a plant is free of lesions and therefore belongs in the clean class and it is the mean yield of the clean plants that determines the percent loss estimate. Any individual differences in placing plants in slight, moderate, and severe categories would not appreciably affect the overall loss estimates. They would only have affected the distribution within classes and the losses assigned to the different classes.

The change in sampling procedures in 1971 was made in anticipation that a more representative field sample would result. Comparative data to show that this was indeed the case are lacking; however, there was a saving in time and effort in the single diagonal sampling method as contrasted to the taking of paired square-yard samples and this is reflected in the larger number of fields sampled in 1971.

The percent losses in the different provinces over the 3 years ranged from a high of 10.2% in Saskatchewan in 1970 to a negative loss, or, in other words, an increase in yield due to root rot, of 3.8% in Manitoba the same year. Whether this increased yield may be significant is a moot point that warrants comment. Examination of the data indicates that the higher yield probably is significant. Disease ratings

were low in the 20 Manitoba fields sampled. In these samples, 30% of the plants were clean and 60% were in the slight class, while only 8% and 2% were in the moderate and severe classes respectively. This is not the usual distribution. In Manitoba in 1969, for example, the distribution was 53%, 27%, 14%, and 6% for the clean, slight, moderate, and severe classes respectively. In 1970, the plants in the moderate and severe categories showed reductions of 20% and 46% respectively, but there were few plants in these classes. Plants with slight lesions, which were greatly predominant, showed an increase in heads of 12% and a yield increase of 6% over the controls. The overall result as noted was a negative loss of 3.8%. Growing conditions were good and moisture was adequate in the summer and fall of 1970 in Manitoba. It may well be that the observed gain in yield reflects the recovery phenomenon noted by Sallans (14), in which recovery from early infections is followed by enhancement of growth and yield over and above the healthy controls.

It is noteworthy that losses were calculated on an individual field basis and the average of these losses was taken to represent the loss in the unit area. If the data for an area had been bulked and the Machacek formula applied, a single atypical field could adversely affect the results. For example, in one crop district, six samples were collected; individually, each showed a loss due to root rot. However, one field from which square-yard samples were taken had a poor crop, had been very densely seeded, and the plants were nearly all in the clean class. In this field the per plant yield was extremely low. When the data for the crop district were bulked, the excessive number of low yielding plants from this one field depressed the per plant yield of the clean class without a parallel decrease in plant yield of the disease classes because there were so few plants from this sample represented in them. As a result, when the Machacek formula, in which potential yield is projected from the per plant yield of the clean plants, was applied a negative loss for the crop district was indicated.

It is suggested that workers assessing disease loss give consideration to the unit on which the losses are computed. In the study reported here, erroneous results would have been obtained on several occasions had the samples from a CD or ARA been treated in bulk, whereas no problem arose when each field sample was treated as a unit.

The most common machine used for seeding on the prairies is the discer. This seeder more or less broadcasts the seed, and depth placement is not precise. A percentage of seeds are left near the soil surface. Such plants have short internodes and are not amenable to classifying by the method used and they were placed in the unclassified category. They may or may not be invaded by the root rot organisms. Observations indicate that shallow seeding results generally in low root rot levels. Agronomic recommendations are for seeding as shallow as is in keeping with the establishment of a good stand. Anderson (2) reported that yields of Manitou, Chinook, and Thatcher wheat were reduced by 23%, 24%, and 33% respectively when seeding depth was increased from 2 inches to 4 inches. If moisture is good, shallow seeding encourages prompt emergence and the plants get off to a quick start. This may be the reason the unclassified category contained more heads and gave higher yields than the healthy.

Plants in the slight, moderate, and severe categories suffered progressive reduction in tillering as evidenced in numbers of heads produced. The results, covering the entire survey, showed reductions of 3.7%, 8.3%, and 15.2% for the three classes as compared with the healthy. Kernel weight reduction was minimal. Representative data taken each year showed only a 6.7% reduction in kernel weight in the severe class. Data are not available on the intermediate classes. Assuming that three components, number of heads, kernel weight, and size of heads, account for total yield, then the reduction in size of heads was 6.3%, which is the difference between the total reduction, 28.2%, and the sum of the reductions in number of heads and kernel weight.

No effort was made to relate soil type to disease levels or losses; however mean losses for the four major soil zones were calculated. In Saskatchewan long-time root rot surveys usually have shown higher disease ratings, and presumably higher losses, under the more droughty conditions often encountered in the brown soil of Zone 1. The rather slight and somewhat variable differences from year to year (Figures 2 to 4) may reflect lower losses due to better than normal rainfall in the short grass zones of the prairies in the years in question. Sallans (14) reported that conditions resulting in yields of less than 16 bu/ac were accompanied by marked increases in common root rot. Such conditions were not experienced during this study.

Protein levels in wheat appear to be little affected by root rot. The slight difference in favor of the grain from severely diseased plants is probably not significant.

The validity of the methods used in arriving at losses may be open to criticism on the grounds that some of the observed loss in diseased plants may be compensated for by the reduced competition they afford healthy plants, which then produce more grain than they would if all plants were free of the disease. This aspect is under investigation.

The close correlation between disease ratings obtained using the 4-class system with weights of 2, 5, and 10 applied to the

slight, moderate, and severe disease classes, and the simple 2-class system is of interest and of practical importance. A survey is much simplified if one has only to determine the percentage of plants diseased, i.e. those with moderate or severe lesions. A conversion factor must then be used to convert these to yield losses. This factor has unfortunately been found to be somewhat variable. In Saskatchewan it was 0.30, 0.45, and 0.27 for 1969, 1970, and 1971 respectively. It is apparent too (Table 6) that there was considerable variability among crop districts. It is thought that variability may be a salient feature in loss from a disease such as common root rot. Disease may occur at any time during plant development. Too, plants may tolerate considerable levels of disease without serious loss if moisture is adequate and temperatures moderate during maturation. On the other hand, harsh conditions during maturation may promote extensive losses from low disease levels. The factor 0.4 determined by Sallans some years ago may be slightly high for presently grown varieties. The mean of the factors determined for the 3 years of this study is 0.33. This figure may be applicable to a simplified survey based on the 2-class system. An alternative is to do a number of loss determinations each year and annually compute a factor based on the relationship of disease rating to loss and then convert the survey disease ratings to loss using the factor obtained.

The average 30 million bushel loss annually for the three provinces is substantial. However, on a percentage basis it is not as high as Machacek reported in his study.

Acknowledgments

Thanks are due to C. S. Shih for statistical guidance in this study, to E. D. Mallough for varietal determinations on the Saskatchewan samples in 1969 and 1970, and to M. S. Bahrey for technical assistance.

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SEED-BORNE BEAN YELLOW MOSAIC VIRUS OF FABABEAN IN CANADA

I.R. Evans[1]

Abstract

Seed lots of fababean (Vicia faba) obtained from several commercial sources in Canada were found to contain seed infected with a seed-borne virus. The virus was identified as a strain of bean yellow mosaic virus (BYMV). The BYMV was readily transmitted from infected to healthy fababeans by the cowpea aphid (Aphis craccivora). In a field trial of fababeans at Guelph natural spread of this virus by aphids from infected to healthy beans was first apparent in early July. At the end of August all of the field grown beans showed symptoms of BYMV. Seeds harvested in October and grown under greenhouse conditions from these plants indicated that on average 1.7% of the seed was infected with seed-borne BYMV.

Introduction

In recent years fababeans, Vicia faba L., have assumed a new importance in Canada as a relatively high protein animal feed crop. A number of cultivars or strains of this bean are currently being tested for their yield and suitability at various locations, primarily in the Western provinces and in the Maritimes.

Fababeans were grown at Guelph for the purpose of rearing Aphis craccivora Koch, the cowpea aphid. Periodically virus-infected bean plants would develop from commercially obtained seed. In light of this fact and the possible future importance of fababeans in Canada a study was undertaken on this seed-borne virus.

Materials and methods

Virus identification

Several lots of seed of the cultivars Broad Windsor and Longpod fababean were obtained from three commercial seed companies in Canada. In all instances 1 to 3 seedlings from each lot of 500 seeds of the two varieties grown under aphid-free greenhouse conditions developed a distinctive mosaic, (Figure 1), indicating a seed-borne virus.

In a host range study mechanical inoculations were made by dusting plant species with 400-mesh Carborundum and rubbing the leaves with a sterile cheesecloth pad dipped into tap water diluted juice from infected bean plants. A minimum of 10 individuals of each plant species was inoculated. After 3 weeks, all inoculated test plant species, irrespective of symptom expression, were checked for virus infection by mechanical sub-inoculation onto pea seedlings, Pisum sativum L. cv. Alaska.

Figure 1. Symptoms of bean yellow mosaic in fababean; top right and below, typical mosaic pattern in leaves; top left, healthy leaf.

The cowpea aphid reared on virus-free fababeans was used in transmission studies.

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Nonviruliferous aphids were starved for 3-4 hours and transferred collectively in groups of 50 or more individuals to virus-infected fababean leaves. After an initial access period of 2 minutes aphids that appeared to be probing were transferred singly to healthy test plants. In all studies with aphids fababean seedlings were used as test plants. Nonviruliferous starved aphids transferred directly to healthy bean seedlings were used as controls.

The physical properties of the virus which included the thermal inactivation point, longevity in vitro and dilution end point were determined in accordance with the procedure suggested by Ross (1964) using Alaska pea seedlings for assaying infectivity.

Epidermal strips taken from the leaves of healthy and virus-infected plants were stained and examined for the presence of virus-induced inclusions according to a method described by Christie (1967). The virus particle morphology was determined by cutting up small pieces of infected or healthy leaf tissue in a few drops of 1% phosphotungstic acid neutralized to pH 6.8 with KOH and containing 0.025% bovine serum albumen. The resulting liquid was transferred to a Formvar coated specimen grid, excess fluid was removed with filter paper, and the specimen was examined with an electron microscope.

Transmission of virus under field conditions

In May of 1972 Broad Windsor fababean seeds were planted in 8 rows 40 m long running in a north to south direction. On June 1 when the beans were approximately 15 cm in height, plants showing virus symptoms were removed. The field plot was then divided into two 20-m halves. The plants in the northern half of the plot in an area where the prevailing wind is southwesterly were all mechanically inoculated with a virus isolate maintained under greenhouse conditions in Broad Windsor. Adjacent to the fababeans, single 40-m rows of Phaseolus vulgaris L. cultivars Bountiful and Dark Red Kidney, and pea cultivars Alaska and Thomas Laxton were planted in mid-June.

Seeds harvested from the fababeans were germinated during the winter of 1973 and checked for seed-borne virus.

Results

Virus identification

The following hosts were susceptible to the seed-borne virus from fababean: Chenopodium amaranticolor Coste & Reyn, and C. quinoa Willd. gave local lesions; Frenchbean (Phaseolus vulgaris) cv. Kentucky Wonder Wax, Kentucky Wonder; pea (Pisum sativum) cv. Alaska, Thomas Laxton, and Crimson clover (Trifolium incarnatum L.) developed a severe systemic mosaic symptom following infection by the virus.

Nonsusceptible hosts were mustard (Brassica juncea Coss.) cv. Tendergreen, cucumber (Cucumis sativus L.) cv. Chicago Pickling, dames violet (Hesperis matronalis L.), Nicotiana clevelandii Gray, N. rustica L., N. tabacum L. cv. Samsun NN, French bean (Phaseolus vulgaris) cv. Bountiful, Dark Red Kidney, Richgreen, Romano, Royalty, and Topcrop, pea (Pisum sativum) cv. Little Marvel, white clover (Trifolium repens L.), and cowpea (Vigna sinensis (L.) Endl.) cv. Black Local. Noninfection of the Phaseolus beans in the host range study indicates the probability that this is a pea mosaic strain of BYMV.

In aphid transmission tests 37 out of 100 cowpea aphids given 2 or more minutes access to an infected fababean leaf transmitted the virus to healthy fababean seedlings.

A study of physical properties revealed that the virus was inactivated at 59 C in crude sap taken from infected fababeans and was not infectious to Alaska pea at sap dilutions greater than 10^{-3}. The virus remained infectious for 60 h but not for 72 h at 21 C in crude sap extracts.

Stained epidermal leaf strips taken from virus-infected fababean leaves and examined with a light microscope revealed the presence of amorphous cytoplasmic inclusion bodies similar to those reported by Bos (1969) and Evans (1969) for bean yellow mosaic virus (BYMV). Electron microscope examination of negatively stained leaf dip preparations revealed the presence of filamentous rods similar to those reported by others for BYMV (Brandes and Bercks 1965, Brandes and Wetter 1959, Taylor and Smith 1968).

Transmission of virus under field conditions

In the field approximately 45% of the mechanically inoculated fababeans showed mosaic symptoms by July 1. These mechanically infected plants were tagged so that seed pods removed at harvest could be collected separately. Natural spread of virus by aphids in the field was first apparent on scattered plants by mid-July. At the end of July all plants in the mechanically inoculated half of the plot showed symptoms of virus infection. About 10% of fababean plants in the downwind noninoculated half of the plot showed evidence of virus infection. This information concurs with the general observation that aphid vectors of plant viruses move in the direction of the prevailing wind; healthy fababeans upwind of virus-infected plants become infected later on in the season than plants downwind (Swenson 1968). By late August all fababeans in the field plot were infected with virus. In the adjacent rows all of the Alaska peas

were virus-infected but no virus infection was apparent in Bountiful or Dark Red Kidney bean or Little Marvel pea. Only one species of aphid, Aphis fabae Scopoli, could be identified as colonizing the field-grown plants. Colonies of A. fabae never built up to more than a few hundred individuals on scattered plants apparently due to decimation of colonies by predaceous insects.

In early October fababean seed was collected from mechanically infected plants, from plants that showed virus infection from natural aphid transmission by late July, and from plants that did not show infection until late August. Seeds grown from mechanically infected plants resulted in 8 out of 454 or 1.8% of seedlings being infected with the virus. From the naturally infected plants 7 out of 510 or 1.4% showed evidence of virus in seed harvested from plants infected by late July, and 9 out of 463 plants or 1.9% had virus in seed harvested from those plants which had shown symptoms by late August. Thus, less than 2% of the seed taken from virus-infected plants was infected with seed-borne virus in this cultivar of fababean.

Discussion

It is concluded from the above evidence that the seed-borne virus in fababean is a strain of BYMV. Its failure to infect cultivars of Phaseolus bean such as Bountiful and Dark Red Kidney formerly would have led to classifying this virus as a strain of the pea mosaic virus, but Box (1970) now regards this virus as a variant of BYMV. The resistance of Little Marvel pea to infection by the virus and the susceptibility of the Alaska and Thomas Laxton cultivars is in agreement with the reports of Corbett (1958) and Ford (1963) for BYMV.

Seed transmission of BYMV in fababean and other legumes has been demonstrated previously (Bos 1970, Corbett 1958). In several Middle Eastern countries this seed-borne virus presents serious problems in the cultivation of fababean (Izadpanah et al. 1969, Kaiser et al. 1967). In Iran, Kaiser (1972) showed that several pathogenic strains of this virus could be isolated from broad beans in different areas of that country. In a planting of 56 fababean types from 14 countries, he showed that BYMV was seed-borne in 80% of the lines with an incidence of 0.1% to 2.4%. In addition to BYMV, at least two other viruses are known to be seed-borne in fababean (Gibbs and Paul 1970, Gibbs and Smith 1970).

At Guelph it has been demonstrated that commercially available fababean in Canada may be infected with seed-borne BYMV. In the field trial natural spread of the virus occurred rapidly in July and August probably as a result of transmission by several species of aphid vectors (Kennedy et al. 1962).

Plantings of fababeans from virus-free seed could become infected with indigenous strains of BYMV from weed or crop sources such as naturally infected red clover and white sweet clover. This is a problem that will have to be looked into if fababeans are to become an established crop, but fababeans imported into Canada and those cultivars currently undergoing agronomic evaluation should be checked for the presence of seed-borne virus. Strains of BYMV present in imported seed lots might be far more pathogenic to fababean than isolates of the virus occurring naturally in North America. However, virus, if present in seed lots, can be controlled under field plot conditions if infected plants are rogued out as soon as symptoms become evident. If these infected plants, which never number much more than 2% of a planting, are removed by early June, then aphid transmission to healthy plants will be prevented and the cultivars freed from virus. This is due to the fact that the virus is totally dependent on the presence of aphid vectors for spread in the bean crop. In most locations in Canada little if any aphid build-up occurs before the end of June (Swenson 1968) and consequently spread of BYMV would not take place in the fababean crop before this time.

Acknowledgments

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OCCURRENCE, EPIDEMIOLOGY, AND CONTROL OF BACTERIAL CANKER OF TOMATO IN SOUTHWESTERN ONTARIO

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Abstract

During the last decade bacterial canker caused by Corynebacterium michiganense has become a serious disease of greenhouse tomatoes in Essex County in southwestern Ontario. Canker caused losses in yield averaging 5-10% annually in 1965-71, with a few individual growers losing up to 60% in a single crop. Perennation of the disease occurs locally. Intensive and continuous tomato cultivation in the Leamington area aids inoculum spread and together with delays in disease detection makes control of canker difficult.

Introduction

Although bacterial canker caused by Corynebacterium michiganense (E. F. Sm.) H. L. Jens. has been known to occur in the U.S.A. since 1909 (10), and has occurred with sporadic frequency in many of the tomato-growing areas of the world (12), it became serious in southwestern Ontario only during the 1960's. For the last 8 years (8) it has been a constant threat to the greenhouse tomato industry centered around Leamington, Ontario, and currently is one of the most dreaded and potentially devastating diseases. This is a report of its epidemiology and factors that render control difficult.

Observations

Occurrence of canker in greenhouse and field crops

In 1961, canker caused almost 100% infection of a 2-acre (0.8 ha) field of staked tomatoes, Lycopersicon esculentum L. cv. Trellis 22, near Leamington, Ontario. By mid-season of 1962, canker affected at least 30% of the plants in two staked crops, one being on the same farm that had the outbreak in 1961. In 1963, the disease affected two greenhouse crops, located on different farms from previous occurrences. One occurred in the spring and one in the fall, and although slightly less than 20% of the plants in both establishments became infected, the rapidity with which the disease spread along the rows was alarming. In 1964, canker was serious in two staked crops, one on the farm with the 1961 outbreak. Although not diagnosed with certainty, canker was also reported to have occurred in a few greenhouse fall crops. Layne and Rainforth (6) observed canker in 21 separate greenhouse plantings in the fall crop of 1965. This involved slightly more than 25 acres (10 ha). They also reported a new systemic fruit symptom of canker. Recognition of this symptom improved the detection of canker, and thereafter made possible more accurate records of its occurrence in greenhouse crops. The disease became more widespread in the 1966 greenhouse plantings. With concerted efforts by plant pathologists and provincial extension specialists at the Harrow Research Station who urged greenhouse growers to follow carefully the recommendations for controlling canker, lower incidences resulted in 1967 through 1969 than in 1965 and 1966. Nevertheless, canker occurred in approximately 20% of the greenhouse establishments in each of the 3 years. Generally, the numbers of infected plants were large in only one or two of the several greenhouses located at each site. In the 1970 crop, there was a substantial increase over the previous 3 years, both in the numbers of greenhouse crops affected and in the overall numbers of plants infected. As in previous years, canker was generally more prevalent in the fall than in the spring crop.

In 1967, Reyes et al. (9) reported canker occurring in 3 of 6 tomato fields examined in Essex County and in 1 of 4 in the adjacent county of Kent. In 1970, within a radius of 6 miles (10 km) of Leamington, I observed canker to be prevalent in 4 of 12 fields grown for the early-basket trade and in 17 of 36 fields of later-maturing crops grown for the processing industry. In 5 of 24 fields of processing tomatoes located farther from Leamington, in Essex County, canker was also found. No canker was observed in 10 field crops examined in Kent County in 1970.

Canker losses and related factors

In general, the disease has been much less serious in field than in greenhouse crops. In the latter, canker causes much

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more severe symptoms in the early spring and the late autumn than during the summer. Under short day culture of low light intensity, systemically infected plants wilt severely and soon die. In contrast, during the summer months infected plants often show barely perceptible wilting of leaves. More commonly, localized tan to brownish, scorch-like necrotic areas (0.5 to 2 cm in diam) on the laminae are characteristic symptoms. In crops that become infected in late May or June, fruit symptoms are scarcely discernible.

Losses in the greenhouse crop have been variable from year to year and from greenhouse to greenhouse even at individual establishments. Losses suffered by individual growers have ranged from less than 5% to as much as 60%. In 1966, most of the 20% reduction in gross yield from the fall crop was attributed to losses from canker. The overall annual yield losses in greenhouse production in the Leamington area from 1965 to 1971 have been estimated to range from 5% to 10%.

As reported by Kendrick and Walker (5), the succulence of the crop markedly determines the severity of infection. Because of high soil fertility resulting from heavy fertilization of the spring cucumber crop, fall plantings of tomatoes following cucumbers almost invariably show greater disease severity than those following tomatoes.

The type of equipment used to irrigate crops affects symptoms, particularly those found on fruits. Where no splashing of the foliage or fruits occurs in greenhouse watering, the "birds-eye" spot is not found. In contrast, the frequent occurrence of this diagnostic symptom in the field readily reveals infection. Birds-eye spot does not harm the quality of the processed fruit but renders those for the early-basket crop unmarketable and is thereby largely responsible for the losses sustained.

Localized infections and systemic invasion of greenhouse plants

The erratic spread of canker in the greenhouse crop has been extremely puzzling and has made the making of control recommendations difficult. Delays of 4-6 weeks and occasionally as long as 3 months between first outbreaks and secondary spread to adjacent plants have often been encountered. To study the cause of these delays an experiment was set up in March, 1970 with potted plants. Michigan-Ohio Hybrid plants 15 inches (37 cm) high growing in 5-inch (12.5 cm) pots of compost soil were used. Sap expressed from the brownish vascular areas of infected fruits and wilted stems was diluted with water in the ratio of 1 to 3 and then rubbed very lightly with the wetted forefinger on the surface of the stems in one series of 12 plants and on the leaves in another series of 12. In the first series inoculum was applied to one side of the stem along the first five internodes above the cotyledons, and in the second series to the upper surface of two leaflets on the third and fourth oldest leaves. Check plants were rubbed with water. Fertilizing schedules were established to maintain a low degree of plant succulence. Six weeks after inoculation, all plants were carefully repotted into 7-inch (17 cm) pots. Blister-like lesions, as reported by Layne (7) and Basu (1), developed in 7 to 10 days on the inoculated leaves. Ten to 20 days later, systemic infection occurred in all leaf-inoculated plants and caused typical unilateral wilting of leaves.

Where stems were inoculated, tan-colored pin-point lesions developed but were not usually discernible before 10 days, and in less succulent plants not before 12-14 days. Thereafter, the lesions enlarged slowly and many were only 1-2 mm in diam 25 days after inoculation. At that time they had whitish borders with tan centers. Lesions continued to enlarge slowly and in 6-8 weeks were 2.0-2.5 mm in diam. Some lesions had coalesced. All were rusty red, projected prominently above stem surfaces and had rough surfaces. After 10 weeks, only 3 of 12 plants had developed systemic symptoms. The lesions continued to increase in size and many had coalesced. Because of excessive sucker production and the care required in the subsequent handling of these potted plants, further observations on systemic invasion were not continued, although the plants were held for 5 more months to determine the longevity of bacteria in the local lesions.

Tissue fragments dislodged from discrete lesions by a superficial scratching with the tip of a scalpel blade were taken at fortnightly intervals after lesion initiation to determine the viability and pathogenicity of the contained bacteria. Microscopic examinations showed that all scrapings contained an abundance of viable bacteria. Concomitantly, when such tissue fragments were inserted into scalpel wounds in young tomato stems, vascular infections typical of canker developed. Eight-month-old lesions proved to be a good source of viable, pathogenic bacteria. Delays in disease spread appear therefore to be associated with slow development of systemic stem lesions and low rates of stem infection in well-hardened plants.

Perennation of canker in Essex County

Extensive laboratory and greenhouse experiments carried out from 1965 through 1968 established that seedborne inoculum was not the source of canker each year in tomato crops of Essex County. Also, critical examinations of many field crops set with transplants imported from Georgia, U.S.A., revealed that these transplants were not the source of infection. By 1969, circumstantial evidence clearly established that the disease was becoming endemic to the area. In several

instances in 1970, field infections were traced to transmission resulting from a previous limited handling of infected greenhouse plants, and similarly infection of greenhouse crops sometimes resulted from the handling of infected field-grown plants. I also traced infection in several processing crops to locally grown infected transplants.

Problems in controlling canker in Essex County

The concentration of 275 acres (110 ha) of steam-heated glass and polyethylene-covered houses, as well as several acres of unheated structures used during the spring for the growing of transplants, means that within an area of about 36 sq miles (93.6 km^2) at Leamington, tomatoes are being grown the year round. In addition, more than 1200 acres (486 ha) for the early-basket trade and about one-tenth of the 7600 acres (3420 ha) in Essex County for the processing industry are grown within the same area. To eradicate canker requires a combined effort by all the individual greenhouse growers as well as all others involved in tomato production and processing. Infection of field-grown tomatoes constitutes a potential source of inoculum for the fall greenhouse crop. As well as transmission by laborers working intermittently in both field and greenhouse crops, there is good circumstantial evidence that windblown inoculum from infected field crops may have been partly responsible for the epidemics in the 1966 and 1970 fall greenhouse crops. In both years a heavy rainstorm accompanied by winds of high velocity occurred when seedlings for the fall crop were half-grown, and sand and bits of plant debris from field crops were blown into the greenhouses.

When canker occurred in the fall greenhouse planting, it usually over-wintered and caused at least a trace of infection in the following spring crop, even where careful sanitation, including steam sterilization of planting containers and soils, had been employed. Bryan and Boyd (3), and Grogan and Kendrick (4) reported that canker bacteria overwintered in tomato debris in the field and in plantbed soil in Georgia and California, respectively. Basu (2) reported that in the absence of host debris the causal bacteria do not survive for more than 3-4 weeks in an unsterilized compost soil at 25 C. The almost continuous tomato production in the Leamington area does not require that canker bacteria survive saprophytically for more than a few days or weeks to serve as a potential inoculum source.

The capacity of canker bacteria to exist superficially on tomato stems at almost "subclinical" levels militates against canker control. The difficulty of recognizing canker in tomato plants growing under "hard" conditions makes detection of the disease very difficult. Also, incipient or mild symptoms on the foliage may easily be overlooked because of the similarity to injury occasionally caused by excess fertilization or by applied pesticides. Delay in detection of canker in the greenhouse crop, where regular handling of the plants in cultural operations is required, has often resulted in extensive and rapid spread of the disease. The smoldering aspect of canker presents a continuing threat to the grower, and the additional daily examinations and extra operations required to detect and prevent explosive secondary spread add significantly to production costs.

The practice of applying sprays of fixed copper at weekly intervals, especially to seedlings, transplants, and young greenhouse plants, has afforded a measure of canker control. However, it has been established that strict adherence to proper sanitation must accompany chemical use.

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OCCURRENCE AND POPULATION DENSITIES OF NEMATODES ASSOCIATED WITH FORAGE CROPS IN EASTERN CANADA

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Abstract

Nine genera of plant parasitic nematodes were associated with forage crops in 560 fields sampled in eastern Canada during 1967-72. Root-lesion, pin, spiral, and root-knot nematodes were present in 96%, 74%, 71%, and 51%, respectively, of all fields sampled; stunt, ring, cyst, dagger, and needle nematodes were found in smaller proportions of the fields. Root-lesion nematodes had the greatest population densities in soils. Population densities of root-lesion and root-knot nematodes were greater in red clover (Trifolium pratense) roots than in alfalfa (Medicago sativa) roots except in New Brunswick. Densities of root-lesion nematodes in roots of birdsfoot trefoil (Lotus corniculatus) were highest in Prince Edward Island. Root-knot nematodes were not recovered from roots of forage grasses from Ontario and Quebec. Cyst nematodes were recovered only from roots of red clover and white clover (Trifolium repens).

Résumé

Durant la periode de 1967-72, notre enquête a révelé la présence de neuf genres de nématodes parasites des plantes associés à des cultures de plantes fourragères, dans 560 champs échantillonnés dans les provinces de l'est du Canada. Des Pratylenchus, Paratylenchus, Helicotylenchus, et Meloidogyne étaient présents dans 96, 74, 71, et 51 pour-cent de tous les champs échantillonnés; des Tylenchorhynchus Criconemoides, Heterodera, Xiphinema, et Longidorus, dans une plus petite proportion des champs. Les populations de Pratylenchus étaient les plus denses dans tous les sols. Les populations de Pratylenchus et de Meloidogyne étaient partout plus denses dans les racines de Trifolium pratense que dans celles de Medicago sativa, sauf au Nouveau-Brunswick. La densité des populations de Pratylenchus dans les racines de Lotus corniculatus était plus grande à l'Ile du Prince-Edouard. Les Meloidogyne étaient absents des racines de graminées fourragères au Québec et en Ontario, tandis que les Heterodera n'étaient présents que dans les racines de T. pratense et T. repens.

Introduction

The potential threat of plant parasitic nematodes to forage production in eastern Canada was recognized by Willis and Thompson (16, 17) when they reported the presence and abundance of root-lesion nematodes, Pratylenchus spp., and eight other genera associated with forage legumes in the Maritime Provinces. Earlier, numerous pin nematodes, Paratylenchus spp., were recovered from the root zone of red clover in Quebec along with species of five other genera (3). Subsequently, Willis and his associates reported, in 1971, the presence and abundance of eight plant parasitic nematode genera associated with three forage legumes in Nova Scotia (18). Potter and Townshend (10) have observed the presence of eight genera of nematodes in soil samples from forage crop fields throughout Ontario. During these years and earlier, the nematology group in the Entomology Research Institute, Ottawa, have noted in the annual report of the Canadian Plant Disease Survey and in the Canadian Insect Pest Review isolated incidences of nematodes associated with forage legumes and grasses in Canada. Coordinated surveys of forage crops were conducted in 1967 and 1968 in southwestern Ontario and in 1971 and 1972 in eastern Ontario, Quebec, Prince Edward Island (P.E.I.), and New Brunswick (N.B.). Though these were carried out over several years, the data are compiled in a single paper to provide a broad inpression of the occurrence, distribution, and numbers of plant parasitic nematodes associated with forage crops in eastern Ontario.

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Materials and methods

All counties of southwestern Ontario were sampled in 1967 and 1968. Sampling routes radiated from the western tip of Lake Ontario through these counties, and samples were taken at 5-mile intervals where possible. Forage fields in eastern Ontario were sampled in 1971. At approximately 10-mile intervals samples were taken along two parallel routes through the counties along the northern shore of Lake Ontario and the St. Lawrence River, and in the Ottawa Valley. In the province of Quebec, forage fields selected at random were sampled in 1971 and 1972 in counties south and east of Montreal and in counties along the north shore of the St. Lawrence River west and east of Quebec City. Forage fields in P.E.I. were sampled in the province's three counties in 1971. Forage fields sampled in N.B. in 1972 were also selected at random in counties with significant forage production.

Samples were taken during September and October in P.E.I. and N. B., during July and August in Quebec, and during May-August in Ontario. In Quebec, N.B., and P.E.I., soil cores were taken to a depth of 20-25 cm through the root zone of randomly selected plants of the predominant forage legume, whereas in Ontario cores were taken through the root zone of all the legume and grass species present. The soil cores from each field were bulked to provide a 1-2 kg sample. Root samples were collected from all fields except those sampled in southwestern Ontario during 1967 and 1968. Ten root systems of each legume and grass species were taken from Ontario fields. In the other provinces, up to 25 root systems of only the predominant legume were taken.

In 1971-72 plant stands were determined in all fields; in southwestern Ontario in 1967-68, the percentage of expected plant stand was determined as based on the knowledge of the local industry and past performance.

The Baermann pan technique (14) was the basic method for the extraction of migratory nematodes from all soil samples collected in eastern Canada. Each soil sample was mixed and passed through a 2 mm screen to remove large roots. Migratory nematodes were extracted from 50-g subsamples for 1 week.

In eastern Ontario and Quebec, cyst and root-knot nematodes were also detected in the samples of heavy soils with a Fenwick can (4) and a bioassay, respectively. These methods supplemented data obtained by Baermann extraction on the frequency of occurrence of both nematodes and provided cysts for species identification. With the Fenwick can cysts were recovered from 50-g air-dried subsamples. For the bioassay, a celery seedling was grown in the remainder of the original soil sample in a 8-cm clay pot held in a greenhouse at 22 C. After 8 weeks the soil was allowed to dry; roots were then shaken free of soil, and 5g of root were placed in a Baermann pan for 2 weeks.

Root samples of legumes and grasses were washed free of soil and the feeder roots were trimmed from the main roots. Migratory nematodes in the Ontario and Quebec samples were extracted from 5g of feeder roots in Baermann pans for 2 weeks, and from 10g of feeder roots in a mistifier for 1 week for the samples from N.B. and P.E.I.

All nematode counts and generic identifications were done by using a dissecting microscope. The population density of each genus of plant parasitic nematode was recorded as the number per 0.45 kg of soil and as the number per g of dry root. After counting, all nematode specimens were killed and fixed for species identification.

All soil and root samples collected in Ontario and Quebec were processed at Vineland Station, Ontario, while those from the Maritime provinces were processed at Charlottetown, P.E.I.

Results

Soils from Ontario and Quebec were generally heavy loams or clays, while those from New Brunswick and Prince Edward Island were generally sandy loams.

Frequency of occurrence

Nine plant parasitic nematode genera were associated with forage crops in eastern Canada (Table 1). Root lession (*Pratylenchus*), pin (*Paratylenchus*), spiral (*Helicotylenchus*), and root-knot (*Meloidogyne*) nematodes occurred in more than 50% of all fields sampled. The frequency of occurrence of the root-lesion nematode varied from province to province by 7% and of the root-knot nematode by 45%.

Root-knot nematode was detected more frequently in soils of Quebec and eastern Ontario when the bioassay was used in addition to the Baermann pan method. Extraction with the Baermann pan indicated that only 22% and 37% of the soils from Quebec and eastern Ontario, respectively, were infested with root-knot nematode. The bioassay detected root-knot nematodes in an additional 14% and 34% of the fields, respectively. Examination of forage legume roots from eastern Ontario indicated another 8% of fields infested. In southwestern Ontario, without a bioassay only 36% of sampled fields were found to be infested in 1967-68.

In P.E.I., three other nematode genera also occurred in more than 50% of the fields

Table 1. Percentage of forage crop fields infested with plant parasitic nematodes in eastern Canada

Nematode	Percentage of fields infested[1] in indicated areas and year					
	S.W. Ontario 1967-68	E. Ontario 1971	Quebec 1971-72	New Brunswick 1972	Prince Edward Island 1971	Eastern Canada 1967-72
Root-lesion	94	100	93	100	100	96
Pin	85	90	63	61	87	74
Spiral	75	80	66	59	65	71
Root-knot	36	79	36	57	81	51
Stunt	43	51	6	24	73	30
Cyst	38	37	20	22	71	34
Ring	10	10	11	69	73	26
Dagger	15	3	4	4	5	6
Needle	0	0	0	0	3	0.5
Fields sampled	99	71	248	51	91	560

[1] % Infestation as determined from soil and from roots of forage legumes (Prince Edward Island, New Brunswick) or forage legumes and grasses (Ontario, Quebec). A celery bioassay was also used to detect root-knot nematodes in eastern Ontario and Quebec.

Table 2. Population density of plant parasitic nematodes in infested samples of soil from forage crop fields in eastern Canada

Province	Mean and range in number of nematodes per 0.45 kg (1lb) of soil								
	Root-lesion	Pin	Spiral	Root-knot	Stunt	Cyst[1]	Ring	Dagger	Total[2]
Southwestern Ontario	810 *20- 6,500*	770 *40- 4,200*	830 *20-7,660*	390 *20-4,900*	280 *20-3,600*	450 *10- 7,300*	170 *10- 650*	130 *20-500*	2,420
Eastern Ontario	1,620 *50-11,700*	2,040 *50-13,600*	1,290 *50-6,300*	560 *100-2,100*	340 *50-1,250*	530 *50- 1,700*	80 *10- 150*	40 *20- 50*	4,810
Quebec	820 *50- 8,300*	470 *20- 3,900*	550 *50-5,400*	940 *20-5,200*	110 *50- 300*	190 *20- 1,200*	90 *50- 250*	70 *10-100*	1,490
New Brunswick	2,100 *200- 7,160*	2,360 *110-18,050*	610 *40-1,990*	1,500 *50-7,850*	420 *50-1,330*	910 *40- 3,750*	320 *40-2,130*	330 *40-630*	4,880
Prince Edward Island	2,800 *310-18,370*	1,370 *100-11,860*	250 *50-1,350*	1,090 *100-8,750*	300 *50-2,100*	1,440 *100-10,000*	150 *50- 770*	30 *10- 50*	5,930
All[2]	1,450	1,100	670	890	300	760	180	100	3,130[2]

[1] Cyst larvae.

[2] The means in the "Total" column and the "All" row, and the grand mean were determined from the original data and not from averaging the means in the table.

sampled; stunt (Tylenchorhynchus) and ring (Criconemoides) nematodes occurred in 73% of the fields, and cyst larvae (Heterodera) in 71%. The needle (Longidorus) nematode occurred in 69% of the fields sampled in N.B.

Population density

Soil samples - In eastern Canada, although the various provinces were sampled in different years and at different times in a season, root-lesion nematodes were present in the greatest numbers (1,450/0.45 kg) followed by pin (1,100/0.45 kg), root-knot (890/0.45 kg), cyst (760/0.45 kg), and spiral nematodes (670/0.45 kg) (Table 2). In each province, one of the four nematode genera occurring most frequently in eastern Canada (Table 1) was always dominant in terms of soil population density, although not always the same nematode was dominant in every province. The mean of the total numbers of all nematode genera per 0.45 kg of soil for each province (Total column, Table 2) probably reflects the differences in sampling times, season, and year. The position of the mean relative to the extremes of the range for each nematode (Table 2) indicates a skewness approximating a Poisson distribution.

Root samples - Rootlets of forage legumes were infested with root-lesion, root-knot, and cyst nematodes (Table 3). Of the legumes sampled in eastern Canada, red clover was the most severely infested except in N.B., where alfalfa was more heavily infested. Root-lesion nematodes were most numerous in red clover roots in each province regardless of sampling time and method of extraction. Red clover roots also contained the most root-knot nematodes in each province except N.B. Cyst nematodes were found only in roots of red clover in all provinces except in eastern Ontario, where these nematodes were recovered also from white clover roots; none were found in either alfalfa or birdsfoot trefoil. Only root-lesion nematodes were recovered from grasses sampled in eastern Ontario and Quebec.

The mean population density relative to the extremes of the range again approximated the Poisson distribution.

Table 3. Population density of plant parasitic nematodes in infested roots of forage legumes and grasses in eastern Canada

Location	Crop and number of samples	Mean and range in number of nematodes per g dry rootlets						
		Root-lesion		Root-knot		Cyst[1]		Total[2]
Eastern Ontario	Alfalfa -61	1,070	10-13,400	2,260	30-16,100	0	0	1,570
	Red clover -31	2,500	10-15,700	9,500	40-39,200	280	30- 770	5,380
	Birdsfoot trefoil -4	150	20- 370	0	0	0	0	150
	White clover -13	1,100	80-15,700	2,050	2,050	440	80- 770	1,350
	Bromegrass -33	1,300	10- 7,400	0	0	0	0	1,300
	Timothy -33	1,300	30- 8,000	0	0	0	0	1,300
	Orchard grass -12	3,380	70-18,500	0	0	0	0	3,380
	Reed canarygrass -2	290	290	0	0	0	0	290
Quebec	Alfalfa -122	660	10- 1,100	2,090	30-12,050	0	0	1,340
	Red clover -95	1,250	10- 1,900	4,640	10-54,600	260	10-1,000	3,550
	Birdsfoot trefoil -3	230	20- 6,670	2,560	2,560	0	0	3,150
	Bromegrass -10	530	100- 1,200	0	0	0	0	530
	Timothy -10	630	300- 1,000	0	0	0	0	630
	Orchardgrass -4	50	50	0	0	0	0	50
New Brunswick	Alfalfa -24	1,640	90-13,300	5,900	300-23,400	0	0	3,540
	Red clover -22	1,700	60- 6,700	1,540	180- 5,400	80	20- 120	2,390
	Birdsfoot trefoil -5	460	70- 950	1,840	260- 4,700	0	0	1,810
Prince Edward Island	Alfalfa -22	1,840	10-15,400	300	50- 670	0	0	1,950
	Red clover -61	7,450	170-46,700	7,300	80-38,400	300	30-1,200	12,900
	Birdsfoot trefoil -8	7,400	60-33,000	760	20- 2,700	0	0	8,010
All[2]	Alfalfa -229	1,060		2,410		0		1,760
	Red clover -209	3,440		5,930		270		6,540
	Birdsfoot trefoil -20	3,310		1,320		0		4,370

[1] Cyst larvae.

[2] The means in the "Total" column and the "All" row, and the three grand means were determined from the original data and not from averaging the means in the table.

Correlation of nematode populations and plant stands

Total populations of plant parasitic nematodes (all genera) associated with forage crops in southwestern Ontario in 1968 were negatively correlated with the percentage of expected plant stand (r=-0.2440; P(0.1)=0.2306). Populations of root-lesion and root-knot nematodes were also negatively correlated with plant stand (r=-0.4503; P(0.1)=0.2306 and r=-0.5287; P(0.1)=0.4124, respectively). In contrast, populations of the other genera were positively correlated with plant stand, as were some comparisons using data from 1971 sampling sites.

Discussion

The genera of plant parasitic nematodes reported in this study to be associated with forage crops are similar to those previously reported from forage crops in Nova Scotia (18), Ontario (10), New Jersey (6), Maryland (5), North Carolina (7), Texas (8), Kentucky (2), and Minnesota (12). Tentative identifications of nematode species indicate that, although essentially the same genera are involved, many species occurring in the southern United States are different from those present in eastern Canada.

The frequencies of occurrence and the population densities of root-lesion nematodes in this study are similar to those reported from forage legume fields in Nova Scotia (18). High population densities and high frequencies of occurrence of root-lesion nematodes together with the previous demonstration of increases in forage yield (13) when these nematodes are controlled indicate that they are an economically important factor in forage production in eastern Canada.

In N.B., more root-knot larvae were recovered from alfalfa roots than from either red clover or birdsfoot trefoil, whereas the converse was true in the other areas. Since essentially the same varieties of alfalfa and red clover are being grown throughout eastern Canada, the reasons for these differences in densities of nematodes in roots of alfalfa and red clover between regions are unknown. They may be coincidental or may result from climatic factors or different species or strains of the nematode. The root-knot nematode has been shown to reduce yields of alfalfa (11) and white clover (1). Because population densities in infested alfalfa root samples were high in this survey, it is likely that root-knot nematodes are economically important in eastern Canada. The cyst nematode has also been shown to reduce yields of forage legumes (9). Although forage yields were not measured, the pin nematode increased to high populations under birdsfoot trefoil (15).

The frequency of occurrence and population densities of pin and spiral nematodes in soil samples from all geographical regions suggest that these nematodes may also affect forage crops.

The survey data showed that root-lesion, root-knot, and total nematode population densities were negatively correlated with the percentage of expected plant stand. However, the wide scatter of points found when nematode populations and plant stands were plotted graphically suggests that such correlations are meaningless. For example, correlations between existing nematode populations and plant stand are based on plants that have survived nematode attack and may be tolerant. To be meaningful, correlations should be based on nematode populations that existed at the time a forage species failed. Thus, controlled field plot experiments offer an alternate method of determining the potential economic loss caused by individual nematode species on individual forage species. In such experiments the range of population densities selected for a nematode species might be determined by the mean population density observed in eastern Canada.

The present survey results emphasize the need for intensive research on all aspects of nematode damage in forage crops in eastern Canada. *Note: see* Addendum, *p. 136.*

Acknowledgment

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Addendum

Since this paper was submitted for publication, an unpublished thesis (Ward 1960) on forage nematodes in New York State has come to the authors' attention. The incidence of Pratylenchus and Paratylenchus in New York State was almost identical to that in Ontario. Helicotylenchus, Meloidogyne and Tylenchorhynchus were found less frequently than in Ontario but they were ranked in the same order of occurrence. In this thesis Ward concluded, as do the present authors, that plant parasitic nematodes are likely a limiting factor in forage production.

Ward, C.H. 1960. Occurrence, distribution and populations of plant parasitic nematodes associated with forage crops in New York State. Ph.D. Thesis, Cornell University. Diss. Abstr. 21:1702. 1961.

TURF GRASS HOSTS OF THREE SPECIES OF NEMATODES ASSOCIATED WITH FORAGE CROPS

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Abstract

A turf grass host range of three nematodes commonly associated with forage crops and turf grasses was determined by examining soil from plots in a turf grass trial containing 73 cultivars in 14 species of grasses. Ten, 10, and 12 species of turf grass were hosts of Pratylenchus neglectus, Paratylenchus projectus, and Helicotylenchus digonicus respectively. Most of the cultivars in the two major grass species tested, Festuca rubra and Poa pratensis, were hosts of these nematodes. The greatest numbers of P. neglectus were found under P. pratensis cv. Delta (14,000/0.45 kg of soil), of P. projectus under L. perenne cv. Kent (65,000), and of H. digonicus under P. pratensis cv. S.21 (27,200). Two of the nematodes, P. projectus and H. digonicus are being reared in a greenhouse on Lolium perenne cv. Kent and P. pratensis cv. Fusa, respectively.

Résumé

Une classe de gazon hôte de trois nématodes associés communément avec les cultures de fourrage et d'herbe de gazons fut identifiée en examinant le sol des parcelles d'un essais d'herbe de gazons comprenant 73 variétés et 14 espèces d'herbe. Dix, 10, et 12 espèces de gazon sont respectivement les hôtes de Pratylenchus neglectus, Paratylenchus projectus, et Helicotylenchus digonicus. La plupart des variétés des deux majeures espèces d'herbe, Festuca rubra and Poa pratensis sont les hôtes de ces nématodes. Le plus grand nombre de P. neglectus fut trouvé sous P. pratensis va Delta à la densité de 14,000/0.45 kg de sol, de P. projectus sous perenne va Kent à la densité de 65,000 et de H. digonicus sous P. pratensis va S.21 à la densité de 27,200. Deux nématodes P. projectus et H. digonicus sont présentement élevés en serre respectivement sur Lolium perenne va Kent et P. pratensis va Fusa.

Introduction

In a forage program at Vineland Station, Ontario, large monospecific populations of root-lesion, pin, and spiral nematodes in natural field soil were required for studies in the greenhouse. Handpicking the nematodes and subsequently increasing the population of each in soil is a tedious and time consuming method of acquiring such monospecific populations in large volumes of soil. Consequently, dominance of one species of nematode over the others in infested field soils was promoted by using preferential dicotyledonous plants. However the presence of the northern root-knot nematode, Meloidogyne hapla, (4) made the use of dicotyledonous plants impractical as this nematode soon overwhelmed the others. Since grasses are not hosts of M. hapla (1) and since the above parasitic nematodes have been observed in turf grass soils in the province, the use of turf grasses to rear these parasitic nematodes in field soils was considered.

This paper presents the results of a turf grass host range study of these three forage nematodes; an evaluation of the ability of each host to support soil populations of each of the genera over an extended period and a recommendation of the grasses considered suitable for the most successful rearing of pure populations of each of the nematodes in tne greenhouse.

Materials and methods

A grass host range of the three nematodes, Pratylenchus neglectus (Rensch), Paratylenchus projectus Jenkins, and Helicotylenchus digonicus Perry, was determined by sampling soil from the 3-yr-old turf grass cultivar trials at the

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Table 1. Turfgrass hosts of four species of plant parasitic nematodes

Grass species and cultivar	No. of nematodes/0.45 kg (1b) soil and host rating*			
	Pratylenchus neglectus	*Paratylenchus projectus*	*Helicotylenchus digonicus*	*Meloidogyne* sp.
Agrostis alba				
Red Top	100 *(p)**	350 *(p)*	50 *(n)*	350 *(p)*
Agrostis palustris				
Penncross	1,600 *(m)*	650 *(m)*	0 *(n)*	200 *(p)*
Smarged	0 *(n)*	0 *(n)*	280 *(p)*	0 *(n)*
Agrostis tenuis				
Exeter	50 *(n)*	150 *(p)*	50 *(n)*	0 *(n)*
Highland	0 *(n)*	100 *(p)*	300 *(p)*	0 *(n)*
Dactylis glomerata				
Tardus II	100 *(p)*	0 *(n)*	2,900 *(m)*	0 *(n)*
Festuca arundinacea				
Backafall	50 *(n)*	0 *(n)*	400 *(p)*	0 *(n)*
Kentucky 31	1,300 *(m)*	300 *(p)*	1,830 *(m)*	0 *(n)*
Manade	1,400 *(m)*	1,400 *(m)*	400 *(p)*	0 *(n)*
S-70	60 *(p)*	0 *(n)*	2,400 *(m)*	0 *(n)*
Festuca ovina				
Duriuscula Durar	0 *(n)*	0 *(n)*	950 *(m)*	0 *(n)*
Festuca rubra				
Arctared	0 *(n)*	7,800 *(g)*	15,400 *(g)*	0 *(n)*
Barfalla	700 *(m)*	350 *(p)*	4,500 *(m)*	900 *(m)*
Boreal	0 *(n)*	150 *(p)*	7,200 *(g)*	0 *(n)*
Dawson	300 *(m)*	1,600 *(m)*	7,100 *(q)*	100 *(p)*
Duraturf	0 *(n)*	0 *(n)*	4,400 *(m)*	0 *(n)*
Echo	0 *(n)*	600 *(m)*	3,000 *(m)*	0 *(n)*
Elco	800 *(m)*	1,200 *(m)*	3,400 *(m)*	300 *(p)*
Erika	800 *(m)*	0 *(n)*	9,200 *(g)*	0 *(n)*
Golfrood	800 *(m)*	4,400 *(m)*	7,200 *(g)*	0 *(n)*
Highlight	50 *(n)*	10,000 *(g)*	7,100 *(g)*	0 *(n)*
Illahee	0 *(n)*	2,900 *(m)*	4,100 *(m)*	0 *(n)*
NFG	50 *(n)*	2,700 *(m)*	3,400 *(m)*	0 *(n)*
Oasis	0 *(n)*	1,800 *(m)*	10,600 *(g)*	0 *(n)*
Olds	50 *(n)*	0 *(n)*	5,300 *(g)*	1,200 *(m)*
Oregon	200 *(p)*	3,800 *(m)*	9,300 *(g)*	0 *(n)*
Pennlawn	200 *(p)*	3,000 *(m)*	4,400 *(m)*	1,300 *(m)*
Polar	500 *(p)*	10,000 *(g)*	15,000 *(g)*	0 *(n)*
Polo	0 *(n)*	4,000 *(m)*	4,000 *(m)*	0 *(n)*
Ruby	50 *(n)*	300 *(p)*	1,600 *(m)*	0 *(n)*
Sceempter	0 *(n)*	100 *(p)*	2,100 *(m)*	0 *(n)*
S-59	0 *(n)*	3,200 *(m)*	11,600 *(g)*	0 *(n)*
Turf	600 *(m)*	2,000 *(m)*	1,000 *(m)*	0 *(n)*
42-14	100 *(p)*	6,600 *(g)*	7,800 *(g)*	0 *(n)*

Table 1. (cont'd)

Grass species and cultivar	No. of nematodes/0.45 kg (lb) soil and host rating*			
	Pratylenchus neglectus	*Paratylenchus projectus*	*Helicotylenchus digonicus*	*Meloidogyne* sp.
Lolium perenne				
Brabantia	500 *(p)*	0 *(n)*	3,000 *(m)*	0 *(n)*
E-10	100 *(p)*	5,100 *(g)*	2,400 *(m)*	0 *(p)*
Kent	2,500 *(m)*	65,000 *(g)*	3,500 *(m)*	150 *(p)*
NK-100	300 *(p)*	8,500 *(g)*	6,300 *(g)*	0 *(n)*
Norlea	2,600 *(m)*	1,000 *(m)*	5,300 *(g)*	50 *(n)*
RVP	1,800 *(m)*	4,500 *(m)*	2,000 *(m)*	0 *(n)*
Viris	250 *(p)*	7,800 *(g)*	800 *(m)*	0 *(n)*
Phleum nodosum				
S-50	100 *(p)*	30,000 *(g)*	1,000 *(m)*	0 *(n)*
Poa compressa				
Commercial Ont.	5,500 *(g)*	100 *(p)*	1,600 *(m)*	0 *(n)*
Commercial U.S.	0 *(n)*	0 *(n)*	500 *(p)*	0 *(n)*
Poa glaucantha				
Draylar	0 *(n)*	0 *(n)*	10,000 *(g)*	0 *(n)*
Poa pratensis				
Aristata	5,200 *(g)*	1,100 *(m)*	2,500 *(m)*	150 *(p)*
Atlas	8,900 *(g)*	100 *(p)*	6,600 *(g)*	0 *(n)*
Baron	7,000 *(g)*	4,000 *(m)*	1,600 *(m)*	300 *(p)*
Captan	11,000 *(g)*	0 *(n)*	8,000 *(g)*	350 *(p)*
Couger	0 *(n)*	3,200 *(m)*	4,500 *(m)*	0 *(n)*
Delft	2,900 *(m)*	700 *(m)*	300 *(p)*	1,300 *(m)*
Delta	14,000 *(g)*	0 *(n)*	24,000 *(g)*	0 *(n)*
Fusa	0 *(n)*	0 *(n)*	14,000 *(g)*	0 *(n)*
Fylking 0217	5,800 *(g)*	2,400 *(m)*	5,900 *(g)*	0 *(n)*
Geary	2,000 *(m)*	1,500 *(m)*	1,400 *(m)*	0 *(n)*
Golf	1,000 *(m)*	450 *(p)*	2,200 *(m)*	1,100 *(m)*
Hunsbella Soma S-644	850 *(m)*	0 *(n)*	4,500 *(m)*	0 *(n)*
Merion	3,000 *(m)*	2,100 *(m)*	300 *(p)*	0 *(n)*
Merion Dutch	3,900 *(m)*	4,800 *(m)*	12,000 *(g)*	0 *(n)*
Nike	5,000 *(m)*	100 *(p)*	8,000 *(g)*	100 *(p)*
Nuggett	7,100 *(g)*	50 *(n)*	8,500 *(g)*	0 *(n)*
Park	180 *(p)*	200 *(p)*	14,000 *(g)*	50 *(n)*
Primo	3,000 *(m)*	400 *(p)*	12,300 *(g)*	0 *(n)*
Prato	1,600 *(m)*	400 *(p)*	6,500 *(g)*	0 *(n)*
Skandia II	2,700 *(m)*	1,000 *(m)*	10,000 *(g)*	0 *(n)*
Skrzeszowice SK-46	2,000 *(m)*	1,300 *(m)*	9,600 *(g)*	0 *(n)*
Spaths	2,000 *(m)*	1,000 *(m)*	10,000 *(g)*	0 *(n)*
Steinacher	0 *(n)*	2,700 *(m)*	6,900 *(g)*	0 *(n)*
Sydsport	6,100 *(g)*	0 *(n)*	4,000 *(m)*	100 *(p)*
S.21	2,200 *(m)*	0 *(n)*	27,200 *(g)*	0 *(n)*
Windsor	600 *(m)*	0 *(n)*	1,500 *(m)*	0 *(n)*
Poa trivialis				
Dasas S-64	1,000 *(m)*	41,500 *(g)*	9,000 *(g)*	0 *(n)*
Ino	3,000 *(m)*	400 *(p)*	3,200 *(m)*	0 *(n)*

* Host rating: n - non-host, 0-50; p - poor host, >50; m - moderate host, >500; g - good host, >5000 nematodes/0.45 kg soil.

Horticultural Research Station, University of Guelph, Preston, Ontario. These plots, located on a sandy loam, contained 73 cultivars in 14 species of grass (Table 1). Soil cores (2.5 x 20 cm) were taken from replicated plots during the summer of 1971. Care was taken to avoid sampling in areas of plots in which clover and dicotyledonous weeds had encroached.

Each 1-2 kg soil sample was screened to remove roots, thoroughly mixed, and a 50-g subsample accumulated from 50 aliquots of soil taken at random. Nematodes were extracted for 1 week from each subsample by the Baermann pan method (4). They were identified to species, and each species was counted, if necessary in diluted suspension, and recorded as the number per 0.45 kg (1 lb) of moist soil. Since the nematode populations had likely stabilized under the 3-yr-old cultivars, they were rated as non-host 0-50, poor host >50, moderate host >500, or good host >5000 nematodes/0.45 kg of moist soil. Nematode extractions were not made from roots because the pin and spiral nematodes are ectoparasites and the root-lesion nematode is a migratory nematode being both in the soil and in the root.

Results

The only plant parasitic nematodes extracted in the Preston turf plots were Pratylenchus neglectus, Paratylenchus projectus, and Helicotylenchus digonicus. A root-knot nematode, not M. hapla, was present but not identified.

Ten of the 13 species of turf grass were hosts of Pratylenchus neglectus. In the two major species of grass tested, 13 of the 23 cultivars of Festuca rubra L. and 3 of the 26 cultivars of Poa pratensis L. were not hosts. Only cultivars of P. pratensis were considered to be good hosts of P. neglectus, particularly P. pratensis cv. Captan and cv. Delta, each of which supported over 10,000 nematodes/0.45 kg of soil.

Ten of the 13 species of grass were hosts of Paratylenchus projectus Three cultivars of Festuca arundinacea Schreb.; 3 of F. rubra, 1 of Lolium perenne L., and 8 of P. pratensis were not hosts. Among the good hosts Festuca rubra cv. Highlight and cv. Polar, L. perenne cv. Kent, and P. trivialis cv. Dasas S-64 were outstanding, supporting 10,000 or more nematodes/0.45 kg of soil.

Twelve species of grass were hosts of H. digonicus. Agrostis alba cv. Red Top, A. palustris Rydb. cv. Penncross, A. tenuis cv. Exeter were not considered hosts. Only F. rubra, L. perenne, and P. pratensis contained cultivars that were good hosts. Poa pratensis cv. Delta and cv. S-21 were outstanding with over 20,000 nematodes/0.45 kg of soil.

Only 5 of the 12 grass species were hosts of an unidentified species of Meloidogyne. Festuca rubra cv. Olds and cv. Pennlawn and P. pratensis cv. Delft and cv. Gulf were only moderate hosts, supporting 1100-1300 nematodes/0.45 kg of soil. Examination of clovers and dicotyledonous weeds in the turf plots did not reveal the northern root-knot nematode, M. hapla.

The best preferential hosts for rearing the pin nematode, P. projectus, were Phleum nodosum (P. bertolonii) cv. S-50 and Lolium perenne cv. Kent. In the greenhouse the latter supported populations of 60,000/0.45 kg of soil in plastic tubs of field soil which initially contained 1 pin nematode per g of soil. Poa pratensis cv. Fusa was selected over other species and cultivars because it did not support the lesion and pin nematodes. A preferential host was not found for rearing the lesion nematode, P. neglectus, because of domination by other nematodes.

Discussion

In North America at least 34 species of plant parasitic nematodes in 18 genera are associated with turf grasses (1). Nine of the genera are quite common and four of them, with a single species in each, were associated with grasses in turf plots at Preston, Ont. These were Pratylenchus neglectus, Paratylenchus projectus, Helicotylenchus digonicus, and a Meloidogyne species which was not the northern root-knot nematode, M. hapla, nor one of the subtropical root-knot species.

The suitability of turf grasses as hosts of each species of nematode was arbitrarily rated though this study involved mixed nematode populations. However the sampling of plots with mixed populations did indicate which nematode species would dominate when attempting to rear the three nematodes in field soils in the greenhouse. Possibly some cultivars would be good hosts if grown on soil infested with a single species of nematode. This rating scheme may be more suitable for P. projectus and H. digonicus than for P. neglectus because the former are found only in soil whereas the latter occurs in soil and roots. Low soil numbers of P. neglectus would not necessarily indicate a poor host, as possibly the roots might contain numerous nematodes. However this study did indicate that many cultivars were hosts of the four species of nematodes.

Twelve, 10, 10, and 5 of the turf grass species were hosts of H. digonicus, P. neglectus, P. projectus, and Meloidogyne sp., respectively. At present there is little possibility of finding turf and forage grasses and forage legumes (5) that do not permit H. digonicus to reproduce. Among the major grass species, however, there is

resistance to the reproduction of P. neglectus and P. projectus; 9 cultivars of F. rubra and 3 cultivars of P. pratensis, were resistant to P. neglectus, and 3 cultivars of F. rubra were resistant to P. projectus. Many of the cultivars of the grass species were derived from a single plant collection from various pasture lands that were further selected in test plots. Apomictic lines were selected in some cultivars of Poa pratensis. One or two cultivars originated with the crossing of established cultivars. However from this background, it was not possible to determine if a single gene or a complex of genes is involved in the resistance.

Correlation of nematode numbers with growth indices was not attempted. Each grass species and cultivar must be considered individually as it is possible that a grass may be sensitive to a small population of a parasitic nematode while another grass may be tolerant to a large population. Though specific problems were not noted in the turf plots, nematodes can be harmful to grasses. In Wisconsin, the spiral nematode, H. digonicus was quite destructive to Kentucky bluegrass (3); in Massachusetts, P. penetrans and T. claytoni were pathogenic to annual rye grass, creeping red fescue and Kentucky bluegrass (6); in Michigan, T. dubius reduced the foliar and root weight of 'Merion' Kentucky bluegrass (2).

The original purpose of this study was achieved. Suitable hosts were found to rear P. projectus and H. digonicus in the greenhouse, the former on Lolium perenne cv. Kent and the latter on Poa pratensis cv. Fusa.

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PLANT-PARASITIC NEMATODE GENERA ASSOCIATED WITH CROPS IN ONTARIO IN 1972

C.F. Marks, J.L. Townshend, J.W. Potter, Th.H.A. Olthof[1], P.W. Johnson[2], and J. Lounsbery[3]

Approximately 1000 soil and root samples from about 40 different crops (Table 1) were processed through the Ontario Nematode Diagnostic and Advisory Service in 1972. The number of samples submitted by extension specialists was similar to that in 1971 (1) and it seems likely that the use of the Service by these workers will stabilize at about 300 samples per year. Direct grower participation in the Service continued to decline, possibly reflecting the increase in routine use of soil fumigation for control of nematodes, particularly by flue-cured tobacco growers.

A survey of about 2500 acres of flue-cured tobacco in the Delhi area showed that root-lesion nematodes, Pratylenchus spp. Filip. 1936, were present throughout the entire area. The population densities were generally low except for a few instances where the soil had not been treated with a nematicide (Table 1). The northern root-knot nematode, Meloidogyne hapla Chitwood 1949,

Table 1. Genera of plant-parasitic nematodes identified from soil samples processed by the Ontario Nematode Diagnostic and Advisory Service in 1972

Crop	No. of samples	Cyst larvae	Root knot	Root lesion	Spiral	Lance	Pin	Stunt	Dagger	Ring	Sheath	Stubby root
Apple	12			1000/11†	150/2		270/9	100/1				
Barley	4			1800/2	200/2		1200/3	50/1				
Bean	2			170/2			320/2	50/1				
Buckwheat	1			850/1	1250/1		700/1					
Cauliflower	1			400/1								
Cherry (choke)	1				1050/1				250/1			
Cherry (sour)	3			600/3	2300/1		50/1			10/1		
Cherry (sweet)	5			230/4			60/2					
Corn	22	270/5		1240/20	80/6		180/4	140/4				
Fallow	20	120/3		440/17	100/2		420/12			50/1		
Grain	1	300/1		850/1	50/1							
Grain (mixed)	3	170/3		880/3								
Juniper	4			570/3								
Lettuce	1			1050/1								
Marigold	1			800/1	50/1		400/1	50/1				
Mushroom	1											
Oat	2			2220/2			300/1					
Onion	4			1050/3	250/3			100/2				
Onion sets	9											
Parsnip	1											
Pea	19			30/1			50/1			50/2		
Peach	20	100/1		520/20	170/7		360/12	180/3	80/6	100/1	700/1	
Pepper	1											
Plum	5			340/4	1620/2		50/4					
Potato	29		610/4	700/26			50/4	100/2				
Raspberry (wild)	1				950/1				250/1			
Rhodendron	3							100/2				40/1
Rose	32			450/18	2700/14		10/1	130/9	200/2			
Rhubarb	3	900/1		1200/1			5300/3					
Rye	6	10/1		1690/5			550/3	50/1				
Strawberry	2			190/2			200/1	100/1				
Tobacco seedbed (burley)	6			1360/6				50/1				
Tobacco seedbed (flue-cured)	1			150/1								
Tobacco (flue-cured)	112	80/3	50/1	1300/100		100/1	100/26	130/19				
Tobacco-survey	567		15/6	180/426	20/157		50/134					
Tomato-field	2			3600/2			90/1					
Tomato-greenhouse	11		1500/10	370/2				50/1				
Violet	1		10050/1									
Wheat	4		50/1	100/1								
Miscellaneous	71			300/12	180/8		110/10	60/11	200/1			

† Average number of nematodes/1b of soil/number of samples containing the nematode.

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was found infrequently and in very low numbers in the area surveyed.

The northern root-knot nematode caused considerable damage to African violets (Saintpaulia sp.) in a commercial greenhouse at Pine Grove, Ontario. Infected plants were unthrifty with dull, wilting, chlorotic leaves; the roots were severely knotted and necrotic. Rooting benches, rooted cuttings, and potted plants for the wholesale market were infested. The general infestation resulted from infested stock plants being grown above the rooting beds and benches of potted plants. The nematodes were readily spread by watering the infested stock. In addition inadequate cleaning of the rooting benches also contributed to the general infestations. The control program recommended, consisting of an application of dimethoate (Cygon 4E, 1 oz/gal of water) as a soil drench once weekly for 3 weeks and every third week thereafter, apparently controlled the nematodes.

As noted previously (1), Table 1 shows that pin nematodes, Paratylenchus spp., are prevalent and thrive on many crops in Ontario. Within this genus P. projectus Jenkins 1956 appears to be the most common species. The new species, Paratylenchus tateae Wu & Townshend 1973 (2) was found associated with corn, alfalfa, and clover in southwestern Ontario and may prove to be more widely distributed.

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REPLANT DISEASE IN APPLE ORCHARD SOIL[1]

R.G. Ross and A.D. Crowe[2]

Abstract

In a pot biossay for the presence of replant disease, Beautiful Arcade apple seedlings grew significantly better in most apple orchard soils fumigated with chloropicrin than in untreated soil. The cause of the poor growth of apple trees in replant orchards in Nova Scotia is not known.

Introduction

In Nova Scotia several apple growers have experienced difficulty in obtaining satisfactory growth of apple trees when replanting apple orchards. The problem did not appear to be associated with poor orchard management. Replant diseases of apple have been reviewed by Hoestra (1) and Savory (3). Hoestra (1) distinguished two types of replant problems; that caused by nematodes, and that due to specific apple replant disease (SARD) of which the cause is unknown. A pot test, comparing the growth of apple seedlings in non-fumigated soil and in soil fumigated with chloropicrin, has been developed to assay for the presence of SARD (4). The results of using this assay on apple orchard soils are reported in this paper.

Materials and methods

The pot bioassay test for SARD was essentially that outlined in a personal communication from D. M. Way, East Malling Research Station, Maidstone, Kent, England. The orchards were all on sandy loam soil and samples from each orchard site consisted of bulked subsamples of the top 22-25 cm of soil. The soil samples were sieved and 3 liters of each placed in each of two 3.6-liter, wide-mouth, screw-cap, glass jars. Chloropicrin, 0.6 ml, was added to each filled jar and the screw cap sealed with Strip Seal weather strip (Tremco Manufacturing Co. of Canada Ltd.). After 7 days the soil was removed and exposed to the air for a least a week during which it was turned twice. A Beautiful Arcade apple seedling at the cotyledon stage of growth was set into each of 10, 11.5-cm clay pots each containing 500 cc of fumigated soil, and 10 pots of non-fumigated soil from each site. The pots of soil from each site were randomized in 10 blocks on the greenhouse bench, hand watered daily, and fed nutrient solution at weekly intervals. When well established the height of the seedlings was measured every 2 weeks.

Results

In 1970, the SARD test was carried out on two soil samples from each of five apple orchards designated A,B,C,D, and E. One sample in each orchard was from a site where young apple trees were growing poorly (poor growth soil) and the other was from a site where growth was satisfactory (good growth soil). The Beautiful Arcade seedlings were transferred to pots of fumigated and non-fumigated soil from each site on April 9 and

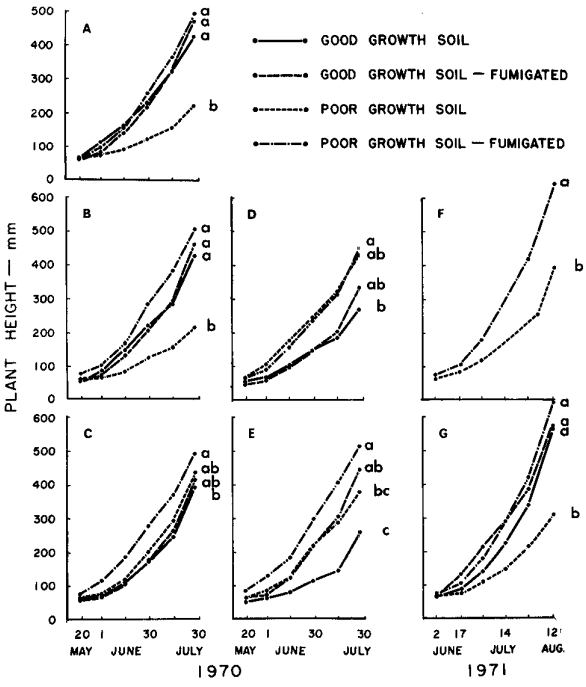

Figure 1. Growth of Beautiful Arcade apple seedlings in chloropicrin fumigated soil and in non-fumigated soil from Orchards A to G. The small letters indicate Duncan's Multiple Range groupings of treatments which do not differ significantly at the 0.01 level.

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the height of the seedlings was measured on the dates shown in Fig. 1.

The growth of the seedlings (Fig. 1) was significantly (P.01) increased by fumigation with chloropicrin in the poor growth soils from orchards A, B, and E, but not in those from orchards C and D. In the good growth soils fumigation had no significant effect on the growth of seedlings from orchards A, B, C, and D, but in orchard E it resulted in a significant (P.01) increase in growth. Orchards A and B were the only ones in which there were significant differences between the growth of apple seedlings in non-fumigated poor and good soils.

In 1971, the SARD test was done on soil from two orchards (F and G). In orchard G, separate soil samples were tested as in 1970 from a site where trees were growing poorly and a site where growth was satisfactory. Orchard F did not have a site where growth was considered satisfactory so the test was done on a single sample from this orchard. The apple seedlings were transferred on May 12 and measured on the dates shown in Fig. 1. Fumigation with chloropicrin significantly (P.01) increased the growth of the apple seedlings in the poor growth soil from both orchards but had no effect on growth in the good growth soil from orchard G.

In 1972, the SARD test was done on soil samples from the Canada Department of Agriculture Research Station at Fredericton, N.B. (orchard H) and Kentville, N.S. (orchards I, J, K, L, M, and N). The origin of the samples was as follows:

Orchard	Site	pH	
H	1	4.7	Area formerly in apples
	2	5.4	Area never in apples
I	1	6.2	Area recently cleared of apple seedlings
J	1	4.9	Area recently cleared of apple seedlings
K	1	4.2	Pears removed, tree sites, area formerly in apples.
	2	4.4	Pears removed, between tree sites, area formerly in apples
L	1	4.9	Apples removed, tree sites
	2	4.6	Apples removed, between tree sites
M	1	4.9	Apples removed, tree sites
	2	5.2	Apples removed, between tree sites
N	1	4.4	Area of poor tree growth
	2	4.2	Area of good tree growth

The Beautiful Arcade seedlings were set in pots of fumigated and non-fumigated soil on October 16 and the growth measured on the dates given in Fig. 2.

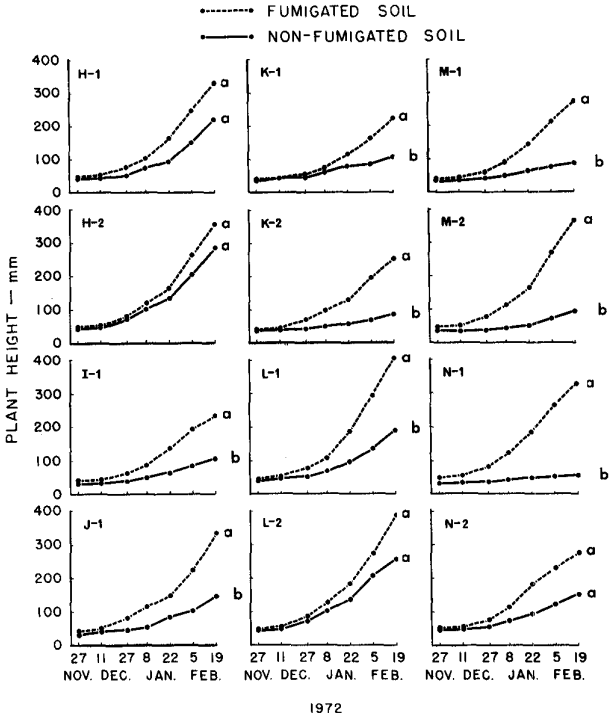

Figure 2. Growth of Beautiful Arcade apple seedlings in chloropicrin fumigated soil and in non-fumigated soil from Orchards H to N. The small letters indicate treatments which do not differ significantly at the 0.01 level.

Fumigation with chloropicrin did not significantly affect the growth of apple seedlings in the apple and non-apple Fredericton soils but, except in soil from the area between tree sites in orchard L and the area of good tree growth in orchard N, it significantly (P.01) increased growth in all Kentville soils. In orchard M the response to fumigation was greater in soil from between tree sites than in soil from the tree sites. Orchard N was replanted in 1968. Its area of poor tree growth included five consecutive trees in the outside row.

Discussion

A response of apple seedlings in soil fumigated with chloropicrin does not necessarily mean that the soil sites are affected by specific apple replant disease (SARD). Several criteria which were discussed by Savory (4) and Hoestra (1) must be established before this can be concluded. However, the results here (Figures 1 and 2) do show that a replant problem exists in Nova

Scotia apple orchards. The cause of SARD is not known but replant problems in the soil may also be caused by such factors as nematodes, high arsenic content, and nutrition (1, 2, 5). Growth may also be better in fresh or non-fruit soil treated with chloropicrin, but Savory (4) points out that the greatest part of the response from fumigation is due to replant effects.

In the 1970 and 1971 tests (Fig. 1) the apple seedling response in the soils from orchards C and D do not indicate that SARD caused the poor tree growth. There was no significant effect from fumigation in soil from either orchard. In orchard E there was a significant response from fumigation in soil from the areas of both good and poor tree growth but there was no significant difference in nonfumigated soil from tne areas of good and poor tree growth. The results from orchards A, B, F, and G suggest that SARD or another replant disorder was present at the sites of poor tree growth. This would also apply to most of the sites sampled in 1972 (Fig. 2).

These tests give no indication that the response was specific for apples. In orchard K the soils were from a pear orchard but the pears were preceded by apples. According to Savory (4) SARD occurs most often in soils with a pH of 6.0 or over. Except for orchard I, which had recently been limed, all the orchards sampled in 1972 had a pH below 6.0.

Because it is not known if the response was specific for apple and the soil sites have not yet been examined for nematodes and other replant disorders, these pot tests do not definitely established the presence of SARD in Nova Scotia apple orchards but they do show that a replant problem exists which can be ameliorated by fumigation with chloropicrin.

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PUCCINIA ALLII ON GARLIC, AN INTERCEPTION

J.A. Parmelee[1]

Abstract

Puccinia allii on garlic (Allium sativum) is recorded for the first time in Canada from intercepted plant material arriving from Europe in personal baggage. The rust is described and illustrated and observations on its taxonomy, distribution and importance are presented.

In late 1971, inspection of baggage arriving from Italy at Dorval Airport, Montreal, Quebec, revealed 1.25 lb of garlic bulbs and leaves with obvious disease symptoms (Figure 1). Examination of the material proved the organism was Puccinia allii (DC.) Rud., a European rust not known to occur in Canada.

Some years ago garlic was grown commercially on a small scale near Winnipeg, Manitoba, but today most of our supply is imported from Spain, California, and Italy. There may be odd plantings in private gardens in and around any large center but garlic production is not of economic importance in Canada today. Why then do we bother reporting an incidence of disease on this plant?

Garlic (Allium sativum L.) is in the onion family, with chives (A. schoenoprasum L.), leeks (A. porrum L.), and of course onion (A. cepa L.) and numerous wild species of Allium. Onions are of commercial significance in Canada and we should ever be alert to the dangers of introducing foreign plant parasites which, on finding new stocks of susceptible hosts, may spread rapidly and may cause considerable loss. Also, Savile (1961) points out that P. mixta on chives may spread to onion when the two plants are grown together. Accordingly it is possible that the same sort of spread may occur with other rusts of cultivated Allium species. This occurrence is worthy of reporting if only to make a description readily available in North American literature. The following description is from this intercepted material.

Uredinia yellowish, amphigenous, telia dull black, amphigenous, long-covered. Urediniospores ellipsoid, slightly flattened 25-31 X 19-23 µm; wall pale yellow 1.0-2.1 µm thick, evenly and finely echinulate, pores 6-8 scattered, indistinct. Teliospores 2-celled, more or less clavate and slightly angular, slightly constricted at septum, 45-77 X 19-32 µm; wall dark red-brown, smooth, occasionally faintly ridged, 3.5-7.5 µm at apex and 0.7-1.0 (-1.4) µm at side; pores not definitely seen, probably absent; pedicel pale yellow, persistent, 7-20 µm long. Teliospores are subepidermal and borne in discrete locules formed by fused brown paraphyses. (Figures 2, 3, 4).

HOST: Allium sativum L. (garlic)

OTHER SPECIMENS EXAMINED: on A. sativum - DAOM 77006, Barcelona, Spain; DAOM 10524 Mista, Malta; DAOM 116473 (=Thuem., Myc. Univ. 1434) Athens, Greece; Sacc., Myc. Ital. 1442. Avellino, Italy.

DISTRIBUTION: P. allii on garlic has a natural range in midsouthern Europe and Asia minor (Savulescu 1953, Fragoso 1924, Sydow P. & H. 1904). In Chile Oehrens (1969) first found the rust on onions, leeks, and garlic in 1968 noting that garlic was the most susceptible host. He noted also that rusted leeks had been reported in Uruguay in 1959. In North America, the only rust on garlic is reported as P. porri (Sow.) Wint. from California (U.S.D.A. Plant Disease Handbook, 1961), but this name has been revised by Cummins (1961) to P. allii.

In Europe, Wilson and Henderson (1966) recognize two autoecious species viz. Puccinia allii Rud. and Uromyces ambiguus (DC.) Lev. Synonomyous with P. allii, they list P. mixta Fckl. and P. porri (Sow.) Wint. as intermediate between it and U. ambiguus. Gaumann (1959) recognizes P. porri because it lacks telial paraphyses and because teliospores are mainly one-celled; however, Wilson and Henderson (1966) claim that P. mixta is the valid name for P. porri if this intermediate is to be recognized. In a study of Corsican fungi, Mayor and Viennot-Bourgin (1951) report P. blasdalei Diet. & Holw. on garlic. They distinguish this rust with numerous one-celled teliospores from P. allii which has a few one-celled teliospores. P. & H. Sydow (1904) recognize these same species by teliospore size, P. allii having slightly larger spores than P. blasdalei (35-80 X 17-30 µm vs. 30-60 X 18-27 µm). In North America, Arthur (1934) treats 3 autoecious species of Puccinia on Allium: P. porri (Sow.) Wint. [=P. mixta Fckl. fide Hylander Jorstad & Nannfeldt (1953), =P. allii Rud. fide Cummins], P. blasdalei Diet. & Holw. [very much like P. allii Rud. according to

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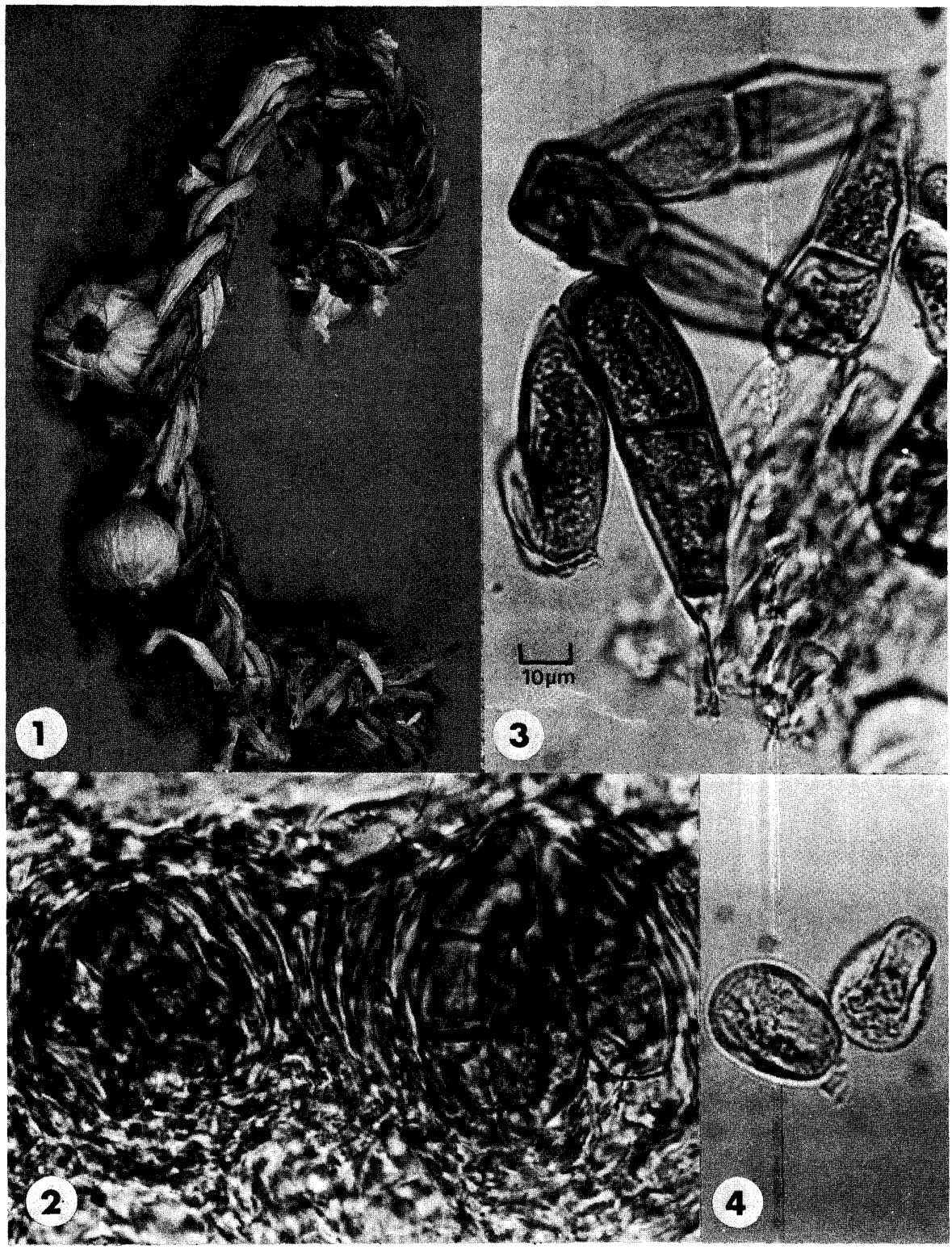

Figures 1-4. *Puccinia allii* on garlic (*Allium sativum*). 1) A twist of garlic, showing small black telia on leaves, X 0.5; 2) Cross-section of a leaf, showing loculate telia bordered by fused paraphyses; 3) Teliospores; 4) Urediniospores. Magnification of Figures 2-4 as shown by scale in Figure 3.

Arthur], and P. granulispora Ellis & Gall. P. porri is the only rust that Arthur records on cultivated Allium. As P. mixta, it is the only one that Conners (1967) has reported on the cultivated Allium cepa L. and A. schoenoprasum L. (chives) in Canada. Savile (1969) also records P. mixta on chives and suggests that at least three biotypes exist in North America. In an earlier paper he (Savile 1961) recognizes P. mixta, P. porri, P. blasdalei, and P. granulispora on small but constant morphological differences and on limited material finds P. allii and P. blasdalei very similar but separable on teliospores characters. He observed P. allii to have smaller spores with hyaline deciduous pedicels compared to colored firm pedicels in P. blasdalei. The latter he records west of the Rocky Mountains and only on native Allium. The characters of the rust reported herein are those of P. allii sensu most European authors but it is apparent from the foregoing that the taxonomy of the rusts on Eurasian Allium requires additional investigation.

In Chile, Oehrens (1969) compared the yield of garlic bulbs by weight (based on 50 bulbs) of a severely infected and lightly infected crop. He reports that rust reduced yield by 83% and noted that the severely infected plants failed to produce flowers and that bulbs were up to 50% smaller in size. In contrast to his own findings, Oehrens states that others do not report significant losses due to this rust.

The European and South American ranges of this rust indicate it to be adapted to Mediterranean climates. Thus the main threat in Canada would be in southwest Alberta, and the Okanagan Valley and southeast Vancouver Island, British Columbia.

Acknowledgment

I have had the benefit of Dr. D. B. O. Savile's observations on Allium rusts and am grateful for his comments about them.

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FLECK AND ACIDOSIS OF POTATOES IN SOUTHWESTERN ONTARIO

C.D. McKeen[1], J.M. Fulton, and W.I. Findlay[2]

Abstract

Two occurrences of necrotic flecking of Irish Cobbler potato foliage in the Harrow area of southwestern Ontario are reported. Growth symptoms observed in 1970 and attributed to acid soil conditions are also reported. The similarity between necrotic flecking and "speckle leaf" which has been established elsewhere as being air pollution injury is discussed.

Observations

Occurrence of disorders and associated symptoms

In late June of both 1966 and 1968 early potatoes in the Harrow-Leamington area of southwestern Ontario developed a black flecking of foliage (Fig. 1). This condition appeared suddenly in both years and came to our attention on June 27, 1966 and June 22, 1968. The flecking developed on both the upper and lower surfaces of the leaf laminae as conspicuous interveinal speckles which enlarged rapidly to produce irregularly shaped, blackish, necrotic areas, some attaining a diameter of 3.5 mm. A slight upward rolling of the affected leaves accompanied the flecking. In 1966 the symptoms were found on many of the young as well as the old leaves of affected plants, but in 1968 the disorder was more restricted to the older leaves. Affected leaves died in a few days and affected plants died prematurely. No estimates of yield reduction were obtained.

In both years these symptoms occurred about 3 weeks after tuberization commenced and 7 to 10 days before digging the early crop began. In growers' fields the disorder occurred in Irish Cobbler, an early-maturing variety which has been grown locally for more than 50 years. There was no evidence of this condition in fields of Avon, another early variety which became popular in the 1960's. A few numbered potato accessions grown in evaluation trials at the Research Station also showed the disorder. No symptoms were seen in Kennebec or Sebago, which are later-maturing varieties.

The irregular pattern of its occurrence in the area was puzzling. It was generally most prevalent on sandy loam soils of coarse texture, and was conspicuously most severe on the high knolls.

Figure 1. Fleck on Irish Cobbler potato foliage. Affected leaf on left, healthy leaf on right.

In late May 1970, about 2 weeks after the first shoots of the early crop emerged, another off-type foliage symptom was observed in two fields of Irish Cobbler near Harrow. The leaves were interveinally chlorotic and the youngest were purplish-red. The laminae were hard in texture and slightly cupped. Affected plants were pronouncedly stunted and occurred in uniformly affected areas on sandy knolls and higher ground. However, after a few days of warmer weather the new growth of affected plants became normal in growth and appearance, although the off-type color of the affected foliage remained apparent for at least 2 weeks.

Probable causes of aberrant growth and related disorders

Several isolation attempts from the necrotic flecks in conjunction with many microscopic examinations failed to yield evidence of the involvement of a pathogen.

The general restriction of these disorders to the sandy soils and the high ground of affected fields suggested a soil-borne factor as the probable cause. A study of the amounts and types of commercial fertilizers applied to these soils revealed that growers had followed standard recommendations. However, soil analyses of the affected areas gave lower pH readings

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than was suspected, this being particularly so on the knolls and high ground. In 1966 and 1968 pH readings in affected areas ranged from 4.9 to 6.2. Analysis of the two field soils where the aforementioned symptoms were observed in 1970 gave pH readings ranging from 4.0 to 4.2 in severely affected areas and 4.9 where the disorder was less severe.

Hooker et al. (3) have described a speckle leaf disease of potato in southwestern Michigan which caused severe yield losses in 1968 and 1969, but was much less serious in 1970 and 1971. In a series of experiments conducted alongside affected commercial potato fields, in plastic houses with charcoal-filtered and non-filtered air, they established air pollution as the cause of the condition. Striking differences in varietal susceptibility were reported. Photochemical oxidants were postulated as the toxic agents. Johnston (4) reported the probable occurrence in 1954 of speckle leaf on potatoes near Guelph, Ontario. He also reported (4) that in recent years growers in the Bradford Marsh have observed serious foliage injury of this nature on the Norland variety.

In June 1971, Probasco (1), the county agent for Accomak and Northamptom counties of Virginia, U.S.A., reported the occurrence of a mysterious leaf-flecking disorder of white potatoes on the eastern shore. It was speculated that the cause was ozone toxicity. A close similarity of symptoms between the potato disorders of Michigan and Virginia and that observed by us in 1966 and 1968 is recognized. Since early potatoes grown in Virginia are normally planted and harvested a few days before similar crops in southwestern Ontario, it seems that these fleck disorders appeared when crops reached a similar stage of development.

"Weather fleck" of tobacco (5) and "bronzing" of white beans (6) have been recognized for several years as serious disorders in southern Ontario. Both are considered to be caused by air pollution. Like potato fleck these disorders occur between flowering and maturing of the affected crops.

Conclusions

The potato fleck symptoms observed by us in 1966 and 1968 may well be the "speckle leaf" disorder attributed to air pollution to which reference has already been made. However, abnormal growth observed in two potato fields in 1970, although it has the common factor of occurring only on the higher ground, does not necessarily have any relationship with the fleck disorder. At the same time, nutrition and soil acidity may play a role in both conditions. It is highly probable that the symptoms observed in 1970 were incited by high soil acidity. Potato growing is not recommended for soils with pH below 4.5. It has been established that manganese toxicity (2) may occur when potatoes are grown on highly acid soil. Characteristic symptoms of excess manganese are described as black flecks and streaks on stems, petioles, and laminae of affected plants. Since stem or petiole streaks were not observed in 1966, 1968, or 1970, manganese levels were not considered as being excessive. A marked drop in the pH of many of the heavily fertilized sandy soils in southwestern Ontario in the last 3 to 5 years is of concern. Soil analyses from several potato fields in 1971 and 1972 gave pH readings ranging from 4.2 to 5.3.

While much is known about toxicity symptoms in several crops caused by specific air pollutants applied in controlled environment chambers, much still remains to be learned about conditions that give rise to injury in the field. Although field and laboratory experiments strongly supported the thesis that ozone and its reaction products are the initiating agents of the "weather fleck" response in tobacco (5) and "bronzing" in beans (6), the concentration of ozone required to bring about the toxic response appears to be dependent upon the physiological condition of the host and particularly of the leaf tissue. Atmospheric conditions are recognized as playing an important role in the development of symptoms in the field but yet are hard to assess because of seasonal inconsistencies. The potato fleck disorder of 1966 appeared after a week of unseasonably hot weather with high daily sunshine, whereas that of 1968 occurred after a period of intermittent days of warm sunny and cool cloudy weather. Abnormally high precipitation occurred in late May of 1968; in 1966 rainfall was normal for April, May, and June. It is possible, on readily leached soils, that large differences in rainfall could bring about nutrient imbalances in the plant that might dramatically affect growth.

While the potato fleck disorder is probably a manifestation of damage from air pollution, it has been associated in its occurrence in southwestern Ontario with high soil acidity; therefore further attention to the possibility that fleck is triggered by high soil acidity in relation to nutritional imbalances seems warranted.

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SEED TRANSMISSION OF POTATO SPINDLE TUBER METAVIRUS THROUGH THE OVULE OF SCOPOLIA SINENSIS

R.P. Singh and R.E. Finnie[1]

Abstract

Potato spindle tuber metavirus was transmitted through the seeds of Scopolia sinensis. Pollination of infected flowers with pollen from healthy S. sinensis plants resulted in 71% infected seedlings, indicating transmission through the ovules. Infected seeds germinated without delay. Symptoms developed within 3-8 weeks after emergence of seedlings and consisted of lesions, necrotic spotting on the leaves, and stunting. In view of the facility with which seed transmission occurs, plants used in seed production should be selected with care.

Introduction

Potato spindle tuber metavirus (PSTM) (2), is known to be seed transmissible in several hosts (1,3,4,5) and has been shown to be transmitted through the pollen and ovule of infected potatoes and tomatoes (1,5).

Scopolia sinensis Hemsley is a local lesion host of PSTM (6,7). Infected plants react by developing local necrotic lesions followed by systemic necrotic symptoms throughout the plant (6,7).

Recently a technique of seed production in Scopolia was developed (2), which enabled us to attempt seed transmission studies with PSTM in order to find out if the pathogen is seed transmissible in this host. The results are the subject matter of this paper.

Experimental and discussion

Sixteen plants of S. sinensis infected with the severe strain of PSTM were set out in the field in 1971. In a separate plot, 400 healthy plants were grown. The plants developed normally and overwintered successfully. The following summer, crosses were made to produce seed, as described by Hanneman and Singh (2). The following crosses were made: healthy x infected, infected x infected, infected x healthy, and healthy x healthy. No fruits resulted from the first two crosses, i.e., where pollen from infected plants was used. Generally, the anthers from infected flowers contained very little pollen and most of them failed to stain with acetocarmine, indicating reduced viability.

Numerous fruits developed in crosses where pollen from a healthy plant was used. Seeds were collected at maturity (6-8 weeks) and stored at 4 C.

The seed obtained from crosses involving healthy pollen were soaked in water in petri dishes for sprouting. The sprouted seeds were individually planted into 3-inch pots containing a greenhouse soil-peatmoss mix. Seedlings were grown with light intensity of 400-600 ft-c and a photoperiod of 14-18 hours, with temperatures ranging from 22-25 C (7).

Three weeks after planting, when seedlings had developed the first pair of true leaves, necrotic lesions or spots (Fig. 1) appeared on the leaves of some seedlings. The lesions generally started at the tip of the leaf, progressing rapidly towards the petiole. Within 2 weeks after the appearance of lesions on primary leaves, additional leaves on the same plant developed lesions, while the primary leaves became chlorotic and dried down. Some plant leaves were ground and sap inoculated to other healthy S. sinensis plants for the determination of the presence of PSTM in seedlings; all tests using plants showing the symptoms were positive for PSTM.

Table 1 shows the data on seed transmission and germination. Of the 1,208 seeds obtained from an infected x healthy cross, 1,090 (90%) germinated. Of these, about 40 seedlings died prematurely before developing true leaves. Of the remaining seedlings, 748 (71%) developed typical systemic symptoms indicating transmission of PSTM through the ovule or maternal tissues. Most of these plants, about 69%, developed symptoms within 3-6 weeks after germination. About 2% of the plants developed symptoms in the 7th-8th week of growth. No seedling obtained from a healthy x healthy cross developed PSTM symptoms.

As was noted earlier, potato spindle tuber metavirus is known to be seed transmissible in several hosts, and the results with S. sinensis were not unexpected. Apart from its significance as further

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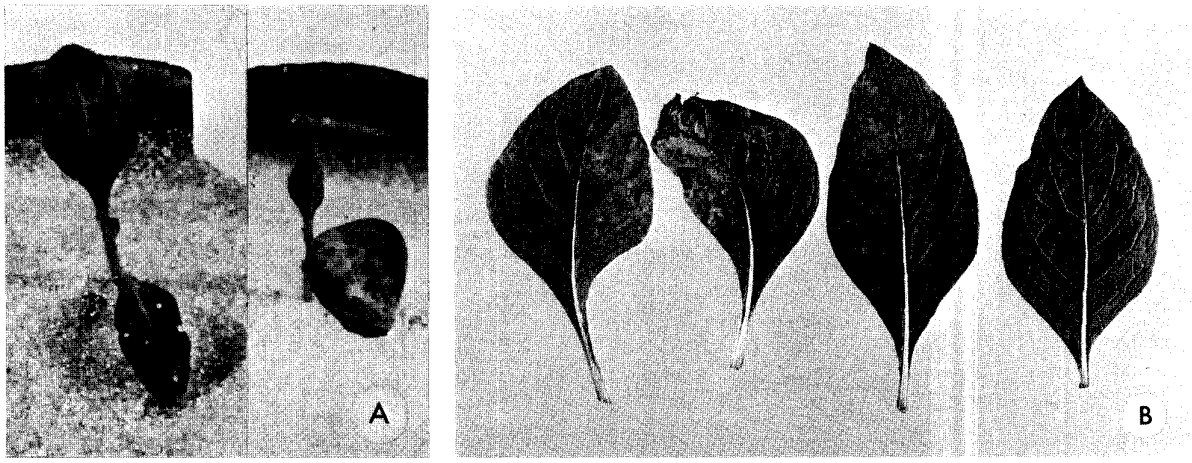

Figure 1. Seedlings of *Scopolia sinensis* grown from seed infected with potato spindle tuber metavirus; A) Necrotic lesions on first true leaves, 2 weeks after seedling emergence; B) Symptoms on first four true leaves of a 6-week-old plant; oldest leaf at left.

Table 1. Seed transmission of potato spindle tuber metavirus in *Scopolia sinensis*

	No. of seeds planted	No. of seeds germinated	No. of seedlings with PSTM symptoms[a]	Percent transmission
Infected x healthy	1,208	1,050[b]	748	71.23
Healthy x healthy	563	504	0	0

[a] About 60 seedlings were indexed by sap inoculation to healthy *S. sinensis* plants for the detection of PSTM and all were positive for PSTM.

[b] Of the 1,208 seeds planted, 1,090 (90%) germinated and of these 40 seedlings died prematurely.

evidence on the mode of transmission of PSTM, this result is of practical importance since it points out the necessity of taking precautions in the selection of mature plants for seed production. Although most of the infected seedlings developed symptoms within 3-6 weeks, and thus could be discarded before being used in any indexing tests, a small percentage of seedlings developed symptoms as late as the 8th week after emergence; if selected earlier these could be mistaken for healthy seedlings and thus complicate the indexing.

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REACTION OF PEA INTRODUCTIONS TO ASCOCHYTA FOOT ROT AND POWDERY MILDEW[1]

S.T. Ali-Khan, R.C. Zimmer, and E.O. Kenaschuk

Abstract

Twelve hundred introductions of peas from a world collection were evaluated for their reaction to foot rot caused by Ascochyta pinodes and powdery mildew caused by Erysiphe polygoni. None of the introductions showed a high level of resistance to A. pinodes; 18 lines showed a light or moderate reaction to powdery mildew in field tests. Only a moderate degree of resistance to powdery mildew was noted.

Introduction

Field peas (Pisum sativum L. var. arvense Poir.) is an important non-cereal crop in Manitoba. Annually, this crop is grown on approximately 50,000 acres, constituting about 75% of the total Canadian acreage. Symptoms of blight and foot rot incited by Ascochyta pinodes L. K. Jones (perfect state, Mycosphaerella pinodes (Berk. & Blox.) Vestgrn.) occur each year in field peas (1). Elsewhere A. pinodes has been shown to cause yield losses as high as 45% (2). Powdery mildew caused by Erysiphe polygoni DC. ex Merat is another disease occurring commonly on peas in Manitoba.

This report presents the results of a seedling test of 1200 pea introductions for resistance to A. pinodes and a field evaluation for resistance to powdery mildew.

Materials and methods

In 1964, seed of 1200 introductions (PI) from 14 countries, was obtained from the Regional Plant Introduction Stations at Ames, Iowa, and Geneva, New York. In 1965, these introductions were grown at the Research Station, Morden, Manitoba, for seed increase and observation. Seed from these plots was used to assess disease reaction to A. pinodes and E. polygoni.

Ascochyta pinodes

To test for resistance to Ascochyta pinodes, plants were grown in perlite at 16-20°C with diurnal illumination of 18 h at 1200 f-c. Ten plants from each of 20 introductions were inoculated in each test. Twelve to 14 days after seeding, a 5 ml aliquot of a distilled water spore suspension containing 2.0×10^5 conidia per ml was placed beside each stem at the surface of the perlite. The suspension contained a mixture of conidia from four cultures of A. pinodes isolated originally from peas grown in different areas in Canada. Single-spore isolates were maintained on an oatmeal agar medium. This medium was used also for inoculum production.

Disease ratings were made 14 days after inoculation and were based on the size of lesions on the region of the epicotyl below the surface of the perlite, as follows:

1 - Lesions 3 mm or less in length.

2 - Lesions 4-9 mm in length.

3 - Lesions 10-15 mm in length.

4 - Lesions 16-20 mm in length.

5 - Lesions larger than 20 mm.

After an initial screening (Test 1), 20 plants from several promising introductions were retested (Test 2). Some tolerant and susceptible plants from these introductions were selected and their progenies evaluated (Test 3) for disease reaction. In Test 3, 12 to 30 plants were used for most introductions; four introductions had less than 10 plants, and for one promising introduction, PI 272157, 104 plants were tested.

Powdery mildew

A visual estimation of severity of powdery mildew was based on natural infection in the field in 1965 and 1966. Severity of infection was rated as:

Light - up to 10% of leaf area infected.

Moderate - 10 to 50% of leaf area infected.

Severe - 50 to 100% of leaf area infected, 50 to 100% of the pods infected.

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[1] Contribution No. 118, Research Station, Agriculture Canada, Morden, Manitoba.

Results and discussion

Ascochyta pinodes - Of the 1200 introductions examined for reaction to foot rot, 29 gave a mean disease rating (MDR) of 1.0-1.9, 541 of 2.0-2.9, 554 of 3.0-3.9, and 76 of 4.0-4.9. One hundred and twelve introductions with an MDR in the range 1.0-2.9 were retested; of these, 85 had an MDR of less than 2.5.

The results presented in Table 1 show the MDR's of 25 introductions selected for subsequent testing on the basis of their performance in the initial test. Upon retesting (Test 2), the MDR value of most introductions was appreciably higher except in those that initially had an MDR of over 3.0. The MDR's of Test 3 agreed closely with those of Test 2 (Table 1).

Table 1. Disease reaction of selected pea introductions to epicotyl inoculation with Ascochyta pinodes

Disease category	PI No.	Mean disease rating* Test 1	Test 2	Test 3	Mean
Moderately susceptible	272157	1.9	2.6	2.8	2.4
	272216	1.5	2.9	3.0	2.5
	180867	2.0	2.9	2.8	2.6
	164523	1.7	3.0	3.0	2.6
	244127	1.8	3.1	3.0	2.6
	272156	1.9	2.9	3.1	2.6
	219706	2.1	2.8	2.8	2.6
	171814	2.3	2.8	3.1	2.7
	174923	2.1	2.9	3.0	2.7
	194340	2.1	2.7	3.2	2.7
	272215	2.0	2.8	3.3	2.7
	269773	1.6	3.1	3.4	2.7
	164285	2.2	2.9	3.3	2.8
	166188	2.2	3.1	3.0	2.8
	180868	2.1	3.1	3.5	2.8
	244125	2.1	3.1	3.1	2.8
	193840	2.1	3.4	3.1	2.9
	Mean	1.9	2.9	3.0	2.6
Susceptible	210565	3.1	3.2	3.1	3.1
	216045	2.7	3.3	3.3	3.1
	263010	2.3	3.6	3.8	3.2
	269805	3.3	3.1	3.6	3.3
	272163	2.9	3.5	3.5	3.3
	272211	2.6	3.4	3.9	3.3
	164838	2.7	3.6	3.8	3.4
	272187	3.2	3.5	3.5	3.4
	Mean	2.8	3.4	3.5	3.2

* Based on a scale of 1-5, with 1 = very light infection and 5 = severe infection.

In most instances introductions in the "moderately susceptible" category (overall MDR <3.0) showed low to moderate ratings throughout the three tests. Similarly, lines in the "susceptible" disease category (MDR >3.0) showed high ratings throughout the three tests. Correlation coefficients between the MDR's of Tests 1 and 2 and between those of Tests 2 and 3 were 0.51 and 0.61, respectively; which were significant at the 5% level of probability. The Mann-Whitney U-Test showed that the differences between the MDR's of the two disease categories were significant in the three tests.

These results indicate that the differences in disease reaction can be distinguished and that they are also transmitted to the progeny. Therefore it should be possible to select PI's and individual plants within them to use in breeding for resistance to A. pinodes.

Some difficulty in reproducing a disease reaction upon retesting was experienced. Factors which may have contributed to this difficulty are genetic heterogeneity within introductions and environmental variations between tests.

Powdery mildew - Due to poor stands in 1965, only 1054 introductions could be rated for mildew resistance. Infection was severe on 865, moderate on 165, and light on 24 lines. In 1966, 183 introductions selected for desirable agronomic characters were retested, with severe mildew infection occurring on 150, moderate infection on 30, and light infection on 3.

PI 201497 gave a light reaction in 1965 and 1966, while PI's 109865, 119795, and 122175 gave a light reaction in 1965 and a moderate reaction in 1966. PI 201391 gave a moderate reaction in 1965 and light reaction in 1966. Moderate reactions in both years occurred in PI's 124480, 162567, 164690, 167205, 171813, 173057, 179451, 183140, 183334, 184130, 195404, 244112, and 244258.

The results indicate that the germ plasm in the world collection shows diversity of disease reaction which appears to be inherited. This offers an opportunity for selection in breeding for increased resistance to ascochyta foot rot and powdery mildew.

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FUNGI ASSOCIATED WITH THE RUSTY ROOT DISORDER OF MUCK-GROWN CARROTS IN ONTARIO

J.C. Sutton[1]

Abstract

Filamentous fungi recovered from carrot roots do not appear to initiate the rusty root disorder of carrots produced in soils at the Bradford and Keswick marshes of Ontario. Species of Alternaria, Cylindrocarpon, Gliocladium, and Fusarium were recovered frequently from carrots grown in eight fields in the marshes, but in pathogenicity tests failed to produce symptoms of rusty root. No filamentous fungus was recovered consistently from carrot roots with symptoms of rusty root. Groups of fungi found in carrots with and without rusty root were similar, but were recovered less frequently from the nonaffected carrots. Although other factors appear to initiate rusty root, the filamentous fungi found in carrot roots are probably important in the development of the disorder.

Introduction

A disorder of carrots (Daucus carota L. var. sativa DC.), referred to as "rusty root" or "early wilt" (1), has damaged a substantial proportion of the carrots grown in the Bradford and Keswick Marshes of Ontario in recent years. Affected carrots characteristically show numerous rusty-brown lateral roots, profuse development of lateral roots, misshapen or stunted tap roots, and stunting and wilting of the foliage. In the field, carrots with rusty root are often distributed in patches that appear larger in successive growing seasons. Parsnip (Pastinaca sativa L.) and dill (Anethum graveolens L.) may also develop symptoms of rusty root. In carrots, similar disorders have been observed in British Columbia (2), Wisconsin (3), Florida (5), and the Netherlands (8).

The cause of rusty root in carrots grown in Ontario is not known, but some observations have indicated that microorganisms may be important in the initiation or development of the disorder. Steam sterilization of affected muck soil prevented rusty root in carrots subsequently grown in the treated soil (unpublished data). Rusty root did not develop on carrots grown in affected soil exposed to about 5 million rads gamma radiation from a cobalt 60 source, but seriously damaged carrots in control soil (Dr. S.G. Fushtey, personal communication). Elsewhere, carrot disorders similar to rusty root have been attributed to species of Pythium (2, 3, 5).

To examine the possible role of fungi in the initiation and development of rusty root, a diagnostic survey of the fungi associated with roots of carrots grown in Ontario muck soils was carried out.

Materials and methods

Carrots were sampled in one field on each of eight farms distributed widely in the Bradford and Keswick marshes on June 16, July 14 and August 14, 1972 (Table 1). Rusty root had appeared during the past 3 years on carrots grown in seven of the eight sampled fields. In field 7 (Table 1) the disease had not been observed in the previous carrot crop grown in 1968. Groups of carrots were lifted with some surrounding soil from 8 to 12 random locations in an area about 40 m diam in each field and bulked. The same areas were sampled at each sampling time. Harvested carrots were stored in plastic bags at about 4 C for 3 to 5 days before plating on agar media. The pH of soil samples was determined by the method of Schofield and Taylor (6). Samples of parsnip and dill with symptoms of rusty root were also collected on July 14 from the Bradford Marsh.

To isolate fungi, pieces of lateral and tap roots of carrot, parsnip, and dill showing various degrees of rusty-brown discoloration were washed in tap water, surface-sterilized, and plated on agar media. About 40 root pieces, 5 mm in length, were cut from each root sample, immersed for 5-10 seconds in 70% alcohol and in 0.5% NaOCl ("Javex"), washed in sterilized distilled water, and plated on water agar, potato dextrose agar (PDA), corn meal agar (Difco), carrot agar, and Martin medium RB-MZ (7). All media except Martin RB-MZ were supplemented with chloretetracycline at 0.1

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Table 1. Location, soil pH, and cropping history of carrot fields, and rusty root severity and sowing times for carrot varieties grown in 1972

Field no.	Location of marsh	Soil pH	Cropping history 1969	1970	1971	Carrot var. grown in 1972	Time of sowing in 1972	Rusty root rating[1] August 14, 1972
1	Keswick	5.9	onions	carrots	onions	Hipack	Early May	3
2	Bradford	5.2	lettuce	carrots	onions	Pioneer 318	Mid May	3
3	Bradford	6.0	onions	carrots	onions	Hipack	Mid May	1
4	Bradford	5.7	carrots	onions	carrots	Hipack	Early May	2
5	Bradford	6.2	carrots	carrots	onions	Hipack	Mid May	3
6	Bradford	5.2	onions	carrots	onions	Hipack	Early May	2
7	Bradford	6.3	onions	potatoes	lettuce	Carousel	Late April	0
8	Bradford	6.0	onions	carrots	onions	Hipack	Mid May	2

[1] In area of field sampled; o = none, 1 = light, 2 = moderate, 3 = severe.

mg/ml. Plates were incubated at 22 C, and examined frequently for fungus growth. Additional fungus isolations were made from the samples collected in August by grinding surface-sterilized root segments in a tissue grinder and preparing dilution plates with the above media. The recovery of Pythium from these samples was attempted by using the method described by Mildenhall et al. (3).

For detection of chytridiaceous and mycorrhizal fungi about 0.5 g of lateral roots from samples collected in July were fixed in formalin-acetic-acid-alcohol, cleared in potassium hydroxide, and stained in trypan blue by the method of Phillips and Hayman (4).

The pathogenicity to carrot roots of fungi recovered frequently from the root segments was examined by growing carrots in muck soil that was sterilized and infested artificially with fungus propagules. Muck soil in which carrots did not develop rusty root in 1972 was collected at the Muck Research Station, Bradford, Ontario, in September, 1972. The soil was autoclaved at 121 C for 30 min, held at room temperature for 2 days, then reautoclaved for an additional 30 min. Spores of three isolates of Cylindrocarpon destructans (Zins.) Scholten, three isolates of Fusarium solani (Mart.) Sacc., two isolates of Gliocladium sp. and two isolates of Alternaria alternata (Fr.) Keissler were recovered in water from cultures grown on malt-extract agar. For each isolate, 10^4 and 10^5 spores were added per g of separate samples of the autoclaved muck soil. In spore suspensions of Cylindrocarpon and Fusarium both macroconidia and microconidia were present. Noninfested and infested soil samples were placed in 16 oz plastic cylinders, and seeds of carrot 'Gold Pak' were sown. The carrots were grown at 8-12 C for 4 weeks and at 16-20 C for a further 4 weeks; the photoperiod was 16 h and light intensity 200-240 uE / m^{-2}/sec^{-1}. The carrot roots were then washed and examined on a dissecting microscope for disease symptoms.

Results

Rusty root symptoms were present on carrot roots collected at each time of sampling from each field except field 7 where no rusty root was found (Table 1).

The fungus genera recovered frequently from the root segments of carrots with symptoms of rusty root were Alternaria, Cylindrocarpon, Fusarium, Gliocladium, Mucor, and Penicillium (Table 2). Species of Penicillium were abundant at each time of sampling. Fusarium and Mucor were recovered commonly only in June and Gliocladium only in July. Cylindrocarpon was the predominant fungus found in July and August, and Alternaria appeared frequently in roots collected in August.

Genera of fungi found in roots collected from the various fields where rusty root developed were similar, but there were quantitative differences, especially in the August samples. In these samples, Cylindrocarpon was the dominant fungus recovered in roots from four fields, Alternaria in roots from two fields and Penicillium in roots from one field.

The fungi recovered from comminuted root segments were generally similar to those found in intact segments, but yeasts and species of Penicillium were notably abundant.

Table 2. Frequency of recovery on agar media of fungi from segments of rusty and non-rusty carrot roots collected at different times in the growing season

Fungus genus	Percent root segments[1]					
	June		July		August	
	Rusty[2]	Non-rusty[3]	Rusty	Non-rusty	Rusty	Non-rusty
Alternaria	0	0	3	0	16	83
Chaetomium	2	0	6	0	2	0
Cladosporium	0	0	6	0	4	5
Cylindrocarpon	2	0	30	12	42	8
Emericellopsis	2	0	4	5	0	0
Fusarium	34	25	10	0	8	8
Gliocladium	0	0	14	0	0	0
Mucor	24	12	10	0	0	0
Papulaspora	0	0	4	0	0	0
Penicillium	27	5	18	0	16	8
Pythium	6	8	4	0	2	0
Rhizoctonia	9	0	5	0	9	4
Rhizopus	6	0	0	0	0	0
Stemphylium	0	0	0	0	2	0
Trichocladium	4	5	0	0	0	0
Trichoderma	8	0	4	0	0	0
Verticillium	0	0	6	0	0	0
Not identified	0	0	4	0	2	0

[1] Percent root segments placed on five selective agar media yielding the fungi indicated.

[2] Samples collected in seven fields where rusty root appeared.

[3] Samples collected in one field where no rusty root appeared.

There were no consistent qualitative differences in the fungi found in segments from rusty- and healthy-appearing portions of the roots from affected carrots.

Fungi found in carrots without rusty root were similar to those with rusty root, but were fewer in number and were usually recovered less frequently (Table 2).

Isolates of Fusarium, Cylindrocarpon, and Alternaria were identified, respectively, as F. solani (Mart.) Sacc. (18 isolates), C. destructans (Zins.) Scholten (15 isolates) and A. alternata (Fr.) Keissler (14 isolates). The isolates were from carrots collected in most of the eight fields sampled.

In pathogenicity tests, neither Fusarium, Cylindrocarpon, nor Gliocladium produced visible symptoms of disease in carrot roots. However, all were reisolated on PDA from 30-60% of surface-sterilised segments of the carrot roots grown in soil infested with 10^4 or 10^5 propagules/g.

Chytrids were numerous in roots collected in July from most fields, but were relatively few in roots from fields 3 and 5 (Table 1). In contrast, 50-100% of the lateral roots of carrots from fields 3 and 4 were mycorrhizal,

whereas carrots from the remaining fields were only 1-12% mycorrhizal.

Fungi recovered from affected parsnip roots were Alternaria, Fusarium, Rhizoctonia, Mucor, and Pythium, and from the roots of dill, Cylindrocarpon, Alternaria, and Penicillium.

Discussion

Filamentous fungi recovered from carrot roots do not appear to initiate the rusty root disorder of carrots produced in the Bradford and Keswick Marsh soils. No fungus species was recovered consistently from carrots that developed rusty root. There were marked differences in the kinds and frequency of fungi recovered from affected carrots harvested at various stages of development and from different fields. Several of the fungi found frequently in carrot roots with the rusty appearance were also found in healthy-appearing roots and in the roots of carrots grown in a field where rusty root did not develop. None of the fungi commonly found in affected roots produced symptoms in carrots grown in sterilized soil infested with large numbers of propagules of these fungi, and under environmental conditions conducive to rusty root development in carrots grown in affected soil.

Pythium was not found to be important in the initiation and development of rusty root which may therefore differ from similar disorders of carrots described previously (2, 3, 5). The fungus was recovered infrequently even when specialized techniques for Pythium isolation were used.

Although other factors appear to initiate rusty root, the filamentous fungi found in carrot roots are probably important in the development of the disorder. There was an abundance of F. solani, C. destructans, and other fungi in carrot roots showing many stages of rusty root development. The ability of several of these fungi to colonize carrot roots which subsequently remain symptomless indicates a possible involvement early in rusty root development.

Crop sequences may influence the prevalence and severity of rusty root. In the seven fields where rusty root appeared in 1972, carrots and onions had each been grown during 1 or 2 of the previous 3 years (Table 1). In field 7, where no rusty root was found, carrots had not been grown during the previous 3 years, and onions were last grown in 1969. Carrot var. Carousel grown in field 7 is known to be susceptible to rusty root (the late C.C. Filman, personal communication).

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