# Assessment of Losses on Spring Wheat Naturally Infected with Barley Yellow Dwarf Virus

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**ABSTRACT**

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An outbreak of barley yellow dwarf in southern Manitoba in 1978 provided an opportunity to study the epidemiology of the disease and to determine losses on wheat (*Triticum aestivum* L.). Sampling of plants with or without the disease in growers' fields revealed 73 and 69% losses in total seed weight per plant of cultivars Glenlea and Neepawa, respectively. The total estimated losses from the disease on bread wheat, calculated for the nine Crop Reporting Districts affected by the epidemic, was 159,260 t (5,851,000 bu) or 7% of the potential yield. Regression analysis of the results with Neepawa indicated a high degree of correlation between yield and the intensity of the disease ($r = -0.97$). Size distribution and most of the milling properties of Glenlea and Neepawa seed were affected by the disease. The percent germination and the weight of plants grown from seed were also lower from diseased than from healthy plants. When three wheat cultivars at four stages of growth in the greenhouse were inoculated with an aphid-nonspecific isolate of barley yellow dwarf virus, Glenlea was the most susceptible to seed yield losses, followed by Sinton and then Neepawa. Losses on these cultivars were progressively lower with later inoculations, but with Sinton and Neepawa, losses were higher at the fourth stage of inoculation (late jointing) than at the third stage (early jointing).

Barley yellow dwarf (BYD) was severe on spring cereals in parts of southern Manitoba in 1978. The disease was particularly severe on wheat (*Triticum aestivum* L.), which provided an opportunity to assess losses from barley yellow dwarf virus (BYDV). Very little work has been done on assessing yield losses on wheat in growers' fields by comparing yields from healthy and diseased plants naturally infected with BYDV. This is particularly true for the spring-type, daylight-sensitive cultivars that are seeded in the spring. In Canada, these cultivars are grown predominantly in the prairies and less in other areas.

Earlier greenhouse and field-plot trials at Winnipeg (3) indicated that all cultivars of spring wheat that were tested, when inoculated at an early growth stage, were very susceptible to damage by the virus. In the field-plot trial, average losses of 64 and 40% in total seed weight per Manitou plant followed inoculation at 20 and 30 days after seeding, respectively, with a *Sitobion avenae* (*Macrosiphum avenae*)-specific virus isolate. Aphid nomenclature in this work follows that of Eastop and Hille Ris Lambers (2).

In this study, we followed the development of the BYD epidemic, assessed yield losses on two wheat cultivars in growers' fields, estimated total losses on wheat in southern Manitoba, examined the relationship between disease intensity and yield loss, and tested grain quality. We also investigated the effect of inoculation with BYDV on three wheat cultivars at different growth stages in a greenhouse trial.

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## MATERIALS AND METHODS

Starting in the second week of June, surveys were made in southern Manitoba to monitor aphid populations, study the development of the disease, and estimate BYD disease incidence and the proportion of late-seeded fields. The eastern part of Saskatchewan was surveyed once in mid-August.

Wheat, oats, and barley plants with symptoms of BYD were collected from different areas of southern Manitoba. Isolation of the virus from each plant was attempted by detaching leaves and placing them in four petri dishes with the cut ends in moist sand. Virusfree individuals of *S. avenae* (Fabricius), *Rhopalosiphum padi* (Linnaeus), *Schizaphis graminum* (Rondani), and *R. maidis* (Fitch) were distributed into the four dishes, one species per dish, and were allowed to feed at 15 C for 2 days. From each dish, 10 feeding aphids were transferred to each of four caged oat (*Avena byzantina* C. Koch 'Coast Black') test seedlings at the two-leaf stage and allowed to feed for 5 days. The aphids were killed by spraying with Dibrome-8 insecticide and the test plants were maintained in a greenhouse for 1 mo before final counts of infected and healthy plants were recorded. Aphids used in these virus isolations were maintained on caged barley plants (*Hordeum vulgare* L. 'Parkland'), and individuals from the colonies were tested regularly to ensure that the colonies were free from virus.

Plants that became infected in the isolation tests were then used as virus source plants for characterizing the isolates according to aphid-specificity or aphid-nonspecificity. The method was similar to that used for virus isolation except that in each trial a fifth aphid species, *Metopolophium dirhodum* (Walker), was also used, and 10 lots of five aphids per species were transferred from the dishes and caged on each of 10 oat test plants.

Loss of seed yield on Neepawa was estimated in a field on the outskirts of Winnipeg and on Glenlea in a field about 20 km from the outskirts. The Neepawa wheat was seeded on 17 May. At anthesis on 8 August, an area of the field was selected that had a dense, even stand of plants, not affected by flooding from rain. The prevalence of infected plants was estimated at 45%. Two parallel transects, each 26 m long and 5 m apart, were run into the field at right angles to the edge. Twenty-four plots, each 1 m × 0.3 m, were marked out along the transects with 1-m intervals between plots. All plants per plot were labeled according to the presence or absence of BYD symptoms.

The original field of Glenlea had been badly flooded by rain and was therefore reseeded on 7 June. On 1 September, a stake was placed in the center of 25 areas of diseased and 25 areas of healthy plants at the hard dough stage. The estimated prevalence of infection in this field was 75%.

All plants in the plots of Neepawa were harvested on 11 September and of Glenlea, on 18 September. Plants from each plot of Neepawa wheat were sorted into diseased and nondiseased groups according to the labels. The number of plants and number of heads per group were counted; heads were detached, air-dried for 1 wk, and thrashed; and the seed was weighed and counted. Diseased plants from each plot of Glenlea were classified into two groups according to height: those 75 cm or less in height (severely stunted) and those more than 75 cm (stunted). Subsequent processing was the same as for Neepawa.

For quality, size distribution, and germination tests, the seed of diseased and nondiseased Neepawa plants was bulked separately, and Glenlea seed was bulked separately for nondiseased, stunted, and severely stunted plants. Individual bulks weighed from 350 to 600 g. For quality tests, samples were milled in a Bühler laboratory mill, and the tests were performed according to standard procedures.

Fifty-gram samples were used in each of three analyses of seed size distribution by sieving. The aperture sizes for the three sieves were 6/64 × 3/4 in., 5½/64 × 3/4 in., and 4½/64 × 1/2 in. Seed retained by these sieves was classified as 1, 2, and 3, respectively, and seed passing the third sieve, as class 4.

In the germination tests, 100 seeds of each bulked sample were sown in an unsterilized bed of soil in the greenhouse. At the early tillering stage (27 days after seeding), the number of seedlings per sample was counted, then the plants were cut at soil level and weighed immediately.

Yield losses from the epidemic of BYD on wheat were estimated as follows: Earlier yield loss trials for wheat cultivars grown in the province (3) and results of the current field crop trials for Neepawa and Glenlea provided values for the mean percent loss per plant per cultivar. Total yields for the cultivars Napayo and Norquay were excluded because no experimental yield loss data for these two cultivars was available. Field surveys provided estimates of the percent of infected plants per field and of the distribution and concentration of late-seeded fields throughout the province. Information on the combined total yield of bread and durum wheat per Crop Reporting District (CRD) (8) and the separate percentage area of bread or durum wheat per CRD, obtained from the Statistics Branch of the Manitoba Department of Agriculture and Manitoba Pool Elevators, respectively, provided the production values for bread wheat per cultivar per CRD.

The percentages of the areas per CRD under one or more of the disease intensity categories (12, 37, 63, and 82%, averaged from the boundary limits of 0–24, 25–49, 50–74, and 75–90% late-seeded fields) were estimated by superimposing the map in Fig. 1 on a map of the CRD boundaries. The total percent loss, a, per cultivar per CRD was obtained from the formula, $a = mn\Sigma(xy)$, where m is the percent loss per plant per cultivar, n is the mean percent incidence of diseased plants per field, and x is the percent area under the relevant disease intensity category, y, per CRD. The potential yield = actual yield × (100/100-a), and the loss in yield = potential yield − actual yield. No yield loss estimates were made for CRDs 4, 5, and 12 because the incidence of infection was seldom more than a trace per field.

A trial in a greenhouse was performed to compare yield losses of Neepawa, Glenlea, and Sinton infected with aphid-nonspecific isolate 7410 (5) and to study the effect of inoculation at four different growth stages on symptom expression and yield. For each cultivar and treatment, two paired, 58-cm rows with 10 plants per row were seeded on 24 October in a bed of soil. One row was inoculated with virus and the other was not inoculated. Treatments consisted of inoculation at 24, 31, 38, or 45 days after seeding, equivalent to stages 3, 5, 7, and 9, respectively, on the Feeke's scale (6). For inoculation, individual plants were caged in 3.8-cm i.d. plastic tubes. Six individuals of *R. padi,* reared on caged plants of Coast Black oats and infected with virus isolate 7410, were dropped into each tube, and the tubes were sealed with Parafilm. After 2 days the aphids were sprayed with Dibrome-8 insecticide and the tubes were removed. The healthy control plants were also caged and sprayed but no aphids were applied. The temperature was maintained at about 16–18 C until after anthesis and then raised to 18–20 C. Supplementary illumination was provided by cool, white fluorescent lamps with a 16-hr photoperiod. Heights of individual plants were measured before harvest on 23 February. Each plant

**Table 1.** Estimated percentages of plants with symptoms of barley yellow dwarf virus in late-seeded fields in southern Manitoba

| Plants infected (%) | Number of fields | | | |
|---|---|---|---|---|
| | | | Barley | |
| | Wheat | Oats | 2-rowed | 6-rowed |
| 0–10 | 12 | 6 | 0 | 0 |
| 11–20 | 10 | 2 | 0 | 1 |
| 21–30 | 8 | 7 | 6 | 2 |
| 31–40 | 10 | 5 | 1 | 2 |
| 41–50 | 17 | 11 | 2 | 0 |
| 51–60 | 6 | 3 | 1 | 2 |
| 61–70 | 6 | 3 | 4 | 1 |
| 71–80 | 7 | 7 | 0 | 1 |
| 81–90 | 1 | 3 | 4 | 0 |
| 91–100 | 0 | 0 | 1 | 1 |
| Total fields | 77 | 47 | 19 | 10 |

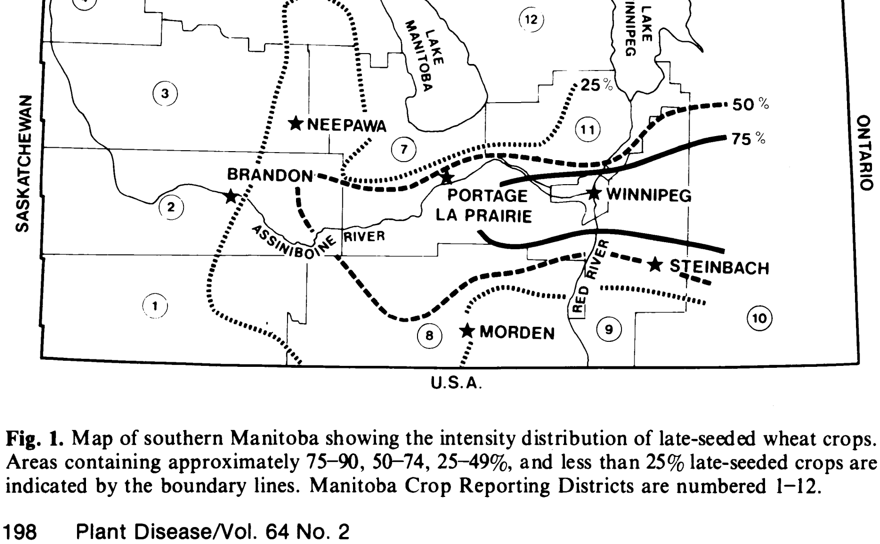


**Fig. 1.** Map of southern Manitoba showing the intensity distribution of late-seeded wheat crops. Areas containing approximately 75–90, 50–74, 25–49%, and less than 25% late-seeded crops are indicated by the boundary lines. Manitoba Crop Reporting Districts are numbered 1–12.

was then cut at soil level and weighed; the number of stems and heads were counted, and the mean length of heads per plant was determined. The heads were thrashed and the total weight and number of kernels per plant were determined.

## RESULTS

**Epidemiology.** Heavy rains during the second half of May delayed the seeding of a portion of the cereal crop in Manitoba. Flooding of many fields also necessitated reseeding the crops seeded earlier. These late-seeded crops, which extended approximately from Brandon to the limits of cultivation in the eastern part of the province, were most affected by BYD. The incidence and distribution of late-seeded fields in southern Manitoba is shown in Fig. 1. Late-seeded crops were sown mainly during the first 2 wk of June. Most crops seeded in areas not affected by the rain were 2–4 wk in advance of the late-seeded crops, and damage from BYD on these was minimal.

A total of 198 fields of late and early seeded cereals was surveyed in Manitoba and eastern Saskatchewan. In southern Manitoba, the estimated percentage of plants infected with the virus in 153 late-seeded fields that were rated for the incidence of BYD, is shown in Table 1. Of these late fields, 12 of wheat, 3 of oats, 5 of two-rowed barley, and 1 of six-rowed barley were revisited on two to four occasions to study the progress of the disease. The estimated mean proportion of infected plants per late-seeded field was 37% for wheat, 45% for oats, 57% for two-rowed barley, and 50% for six-rowed barley. In eastern Saskatchewan, the incidence of plants with symptoms was seldom more than a trace per field.

The first aphids, all *S. avenae*, were detected on 19 June and the first *R. padi* were found on 28 June. Populations remained very low until 3 July when numbers increased markedly after 6 days of persistent southerly winds. Populations appeared to peak during 10–14 July, about 2 wk after the first *R. padi* were found. At the stage of peak populations, *R. padi* and *M. avenae* were the most common species, with the former predominating. Small populations of *M. dirhodum* and traces of *R. maidis* were also found. At this time aphids were found almost exclusively on late-seeded crops. By 21 July, populations had declined markedly and by 26 July aphids were rare or absent.

The first symptoms of BYD on plants in late-seeded wheat crops were detected on 13 July when aphid populations were at their peak and plants were at the late jointing to early heading stage. Infected plants were scattered very thinly through the fields, either singly or as small groups. Symptoms consisted of stunting of the plant and slight chlorosis of the leaves, with or without very mild yellowing of the leaf tips. The mean incidence of plants with BYD symptoms was 2% per field. By 26 and 27 July when these crops were at the flag-leaf to headed stage, symptoms consisted of mild leaf yellowing. Patches of infected plants up to 1.25 m in diameter, with the most stunted in the center, occurred throughout the fields. Plants with symptoms averaged 7% per field. By 1 August (plants at the flag leaf to soft dough stage), symptoms from further secondary spread of the virus were beginning to appear. These symptoms were much more apparent than those on plants infected earlier, the two uppermost

**Table 2.** Comparative transmissibility of 25 barley yellow dwarf virus isolates[a] with five species of aphids as vectors

| Source Isolate No. | *Sitobion avenae* | *Metopolophium dirhodum* | *Rhopalosiphum padi* | *Schizaphis graminum* | *R. maidis* |
|---|---|---|---|---|---|
| Barley | | | | | |
| 7801 | 19/20[b,c] | 9/20 | 19/19 | 9/20 | 3/20 |
| Oats | | | | | |
| 7802 | 12/20[c] | 17/20 | 19/20 | 3/20 | 1/20 |
| 7803 | 8/20[c] | 11/19 | 18/20 | 5/20 | 1/19 |
| 7804 | 8/20[c] | 2/20 | 19/20 | 2/20 | 1/20 |
| 7805 | 11/20[c] | 7/20 | 20/20 | 6/20 | 3/20 |
| 7806 | 4/9 | 3/10 | 8/10 | 1/10 | 0/10 |
| Wheat | | | | | |
| 7807 | 5/10 | 0/8 | 10/10 | 1/9 | 0/10 |
| 7808 | 7/10 | 7/10 | 10/10 | 5/10 | 2/10 |
| 7809 | 4/10 | 1/10 | 10/10 | 1/10 | 0/10 |
| 7810 | 5/10 | 4/10 | 8/10 | 1/10 | 0/10 |
| 7811 | 10/20[c] | 11/20 | 16/19 | 1/20 | 0/20 |
| 7812 | 8/10 | 8/10 | 9/10 | 2/10 | 0/10 |
| 7813 | 2/10 | 0/10 | 9/10 | 3/10 | 0/10 |
| 7814 | 12/20[c] | 8/20 | 18/18 | 3/20 | 0/20 |
| 7815 | 2/10 | 1/10 | 9/9 | 1/10 | 0/10 |
| 7816 | 8/10 | 4/9 | 9/9 | 3/10 | 2/10 |
| 7817 | 6/10 | 3/10 | 10/10 | 3/10 | 0/10 |
| 7818 | 4/10 | 2/10 | 10/10 | 1/10 | 0/10 |
| 7819 | 4/10 | 0/10 | 6/10 | 2/8 | 0/10 |
| 7820 | 4/10 | 0/10 | 10/10 | 2/10 | 0/10 |
| 7821 | 8/10 | 6/10 | 8/9 | 0/8 | 0/8 |
| 7822 | 2/10 | 3/10 | 9/9 | 5/10 | 0/10 |
| 7824 | 6/10 | 1/10 | 9/10 | 2/10 | 0/10 |
| 7825 | 2/10 | 5/9 | 9/10 | 1/9 | 0/10 |
| 7827 | 4/10 | 3/10 | 9/9 | 2/9 | 0/10 |

[a] Isolated from plants naturally infected in the field.
[b] Number of Coast Black oat test plants infected of the number infested with five aphids per plant. Aphids were allowed a 2-day feeding period on the virus source, followed by a 5-day inoculation feeding period on the test plant.
[c] Two trials were performed with 10 oat plants per aphid species per trial. Only one trial was performed with the other isolates.

**Table 3.** Effect of barley yellow dwarf virus on yield components of two wheat cultivars in field crops

| Cultivar | Mean no. of plants per plot[a] | | Mean no. of heads per plant | | | Mean seed weight per plant (g) | | | 1,000 kernel weight (g) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Healthy | Diseased | Healthy | Diseased | Percent reduction | Healthy | Diseased | Percent reduction | Healthy | Diseased | Percent reduction |
| Neepawa | 38 | 30 | 2.1 | 1.6 | 24 | 1.16 | 0.36 | 69 | 25.7 | 17.7 | 31 |
| Glenlea | | | | | | | | | | | |
| Stunted[b] | 27 | 28 | 3.0 | 2.8 | 7 | 3.86 | 1.54 | 60 | 38.5 | 24.4 | 37 |
| Severely stunted[b] | ... | 30 | ... | 1.5 | 50 | ... | 0.54 | 86 | ... | 25.8 | 33 |

[a] There were 24 plots for Neepawa and 25 each for healthy, diseased-stunted, or diseased-severely stunted Glenlea.
[b] Severely stunted plants were 75 cm or less (mean minimum height = 38 cm); stunted plants were taller than 75 cm (mean maximum height = 93 cm); healthy plants had a mean height of 99 cm.

leaves on infected stems being strongly yellowed. At this stage, the mean proportion of plants with symptoms was 12% per field.

Hot weather during the second week of August caused premature dieback of the yellowed leaves. Leaves on symptomless plants remained green. By 15 August (plants at the soft to hard dough stage), approximately 22 days after aphids were no longer detectable, the incidence of plants with BYD symptoms had stabilized at a mean of 37%. Near harvest time, early infected plants could be readily recognized by the moderate to severe stunting. These plants were surrounded by later infected plants with only slight or no stunting but with partially filled heads. On both early and later infected plants, heads on infected stems and prematurely dead leaves were darker than on symptomless plants. This darker color, particularly in the heads, was presumed to result from invasion by bacteria and fungi. Because heads on healthy plants were not discolored, BYD may have predisposed the heads to the secondary infection.

In tests to determine prevalent virus variants, BYDV was isolated from all of 23 wheat, 8 oat, and 5 barley plants sampled in the field. Twenty-five of these isolates, characterized by attempted transmission with five aphid species, showed transmission patterns characteristic of the aphid-nonspecific variant; *R. padi* was the most efficient vector (Table 2). Of the remaining 11 isolates that were not tested with five aphid species, eight were transmitted from field samples by *S. avenae* and *R. padi* and one also by *S. graminum* and thus appeared to be aphid-nonspecific. Two isolates were transmitted only by *R. maidis*, thus appearing to be specific for this aphid. Most of the aphid-nonspecific isolates caused very severe stunting of the test oats, especially with plants inoculated by *R. padi*.

**Table 4.** Size distribution[a] of seed from healthy and barley yellow dwarf virus-infected wheat cultivars

| | Percent of total seed weight | | | | |
|---|---|---|---|---|---|
| | Neepawa | | Glenlea | | |
| Seed class[b] | Healthy | Diseased | Healthy | Stunted[c] | Severely stunted[c] |
| 1 | 62.2 | 21.5 | 78.2 | 46.2 | 54.0 |
| 2 | 16.3 | 20.2 | 10.2 | 16.2 | 14.2 |
| 3 | 16.9 | 40.2 | 8.7 | 23.9 | 20.1 |
| 4 | 4.6 | 18.1 | 2.9 | 13.7 | 11.7 |

[a] For each treatment per cultivar, 50-g lots were sieve-screened in triplicate, and screenings per class were weighed.
[b] Aperture sizes in the three sieves on which seed classes 1, 2, and 3 were retained were 6/64 × 3/4 in., 5½/64 × 3/4 in., and 4½/64 × 1/2 in. Class 4 was seed that passed through the third sieve.
[c] Severely stunted plants were 75 cm tall or less; stunted plants were more than 75 cm tall.

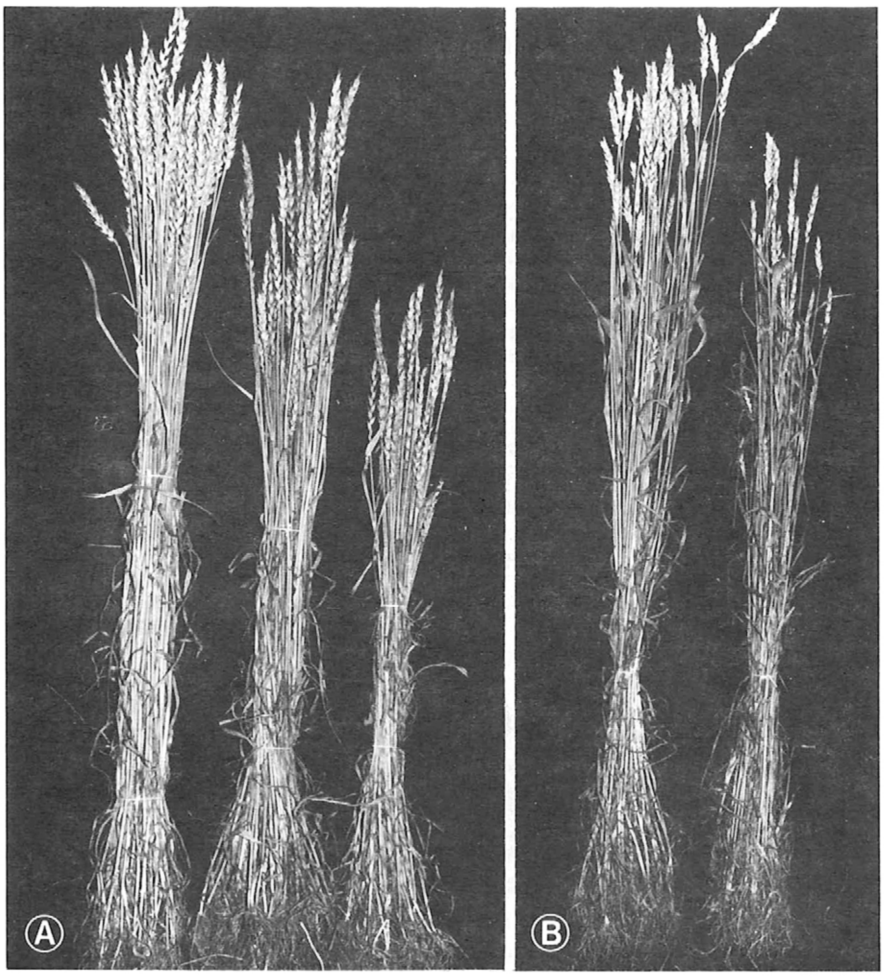


**Fig. 2.** Representative sample sheaves each with 20 plants of **(A)** Glenlea and **(B)** Neepawa spring wheats from growers' fields. The left sheaf of each cultivar shows healthy plants. Other sheaves contain plants infected with barley yellow dwarf virus. Those of cultivar Glenlea are designated stunted and severely stunted.

**Effect of BYD on yield in field crop tests.** The mean loss in seed weight per Neepawa plant was 69%. Stunted Glenlea plants lost an average of 60% in yield, and severely stunted plants lost 86% (Table 3). The number of heads per plant and the 1,000 kernel weights were also reduced. The degree of stunting on BYD-infected plants is illustrated in Fig. 2.

**Yield and disease intensity.** The relationship between yield and disease intensity for Neepawa was examined by regression analysis of the data from the field crop trial. Total plants per plot ranged from 50 to 96 with a mean of 68. For each of the 24 plots, the total actual yield was first expressed as a percent of the potential yield with the formula,

$$\frac{W}{W_1 \times N} \times 100,$$

where W = total weight of seed per plot, $W_1$ = mean weight of seed from all healthy plants, and N = total number of healthy and diseased plants (1,7). A linear regression line derived from the regression formula, $Y = 98.24 - 0.65X$, fitted closely to the points on the graph and passed close to the theoretical expectation of 100% yield with zero infection. With 100% infection, the yield value was 33%, close to the value of 31%, derived arithmetically from the tabulated data. The degree of correlation was high between percent of yield and percent of diseased plants ($r = -0.97$) (Fig. 3).

**Size distribution, germination rates, and milling properties of Neepawa and Glenlea seed.** The distribution of seed size according to weight is shown in Table 4. The proportion of the largest seed was markedly reduced by virus infection. The proportion of very small, shriveled seed from infected plants was also much larger. Interestingly, there was less reduction in the proportion of large seed for severely stunted Glenlea than for stunted Glenlea.

Germination percentages were reduced for seed from infected plants (Table 5). The fresh weight of the 27-day-old seedlings grown from seed of the infected plants averaged 22–28% less than that of seedlings from seed of healthy plants. These results were similar to those found in earlier studies with 2-rowed barley (4). Panayotou (9) recently also reported that the percent germination of seed from BYDV-infected oat and barley plants was lower than that from healthy plants. This was not the same for wheat, however. Seedlings derived from seed of diseased oats and barley were also poor in vigor.

Most milling properties of Neepawa and Glenlea grain were affected by the disease, and trends between the results for healthy and diseased seed were similar for both cultivars (Table 6). Stronger flour was indicated by the slope of the mixographs even though the mixing times of healthy samples were slightly longer than those of diseased samples. The higher sedimentation values and lower yields from diseased samples could be explained by the higher content of protein in the whole wheat and the flour.

**Estimation of losses on wheat in southern Manitoba.** Losses in seed yield on bread wheat in 1978 were estimated for Manitoba CRDs 1, 2, 3, 6, 7, 8, 9, 10, and 11 (8). Values for the loss per plant per cultivar were derived for five of the seven cultivars grown in Manitoba in 1978. The 69 and 73% mean losses per plant for Neepawa and Glenlea, respectively, found in the current field crop trials were used for these two cultivars.

With Sinton, the fourth stage of growth in the current greenhouse trial was close to the average stage of growth at which infection occurred in the field. Therefore, the 67% loss value found for inoculation at this stage was accepted for this cultivar.

An earlier experiment showed a 40% loss of Manitou inoculated with a *S. avenae*-specific isolate in field plots at the early jointing stage (3). Because aphid-nonspecific isolates clearly predominated in the 1978 epidemic and because most aphid-nonspecific isolates cause more severe losses on cereals than do *S. avenae*-specific isolates (Gill and Comeau, *unpublished*), a value of 50% was accepted for Manitou. In greenhouse comparative tests, Selkirk was as susceptible as Manitou (3). Thus, 50% loss per plant was also accepted for this cultivar.

The total production for the five cultivars in the nine CRDs affected by the epidemic was 2,123,187 t (78,001,000 bu). The estimated total loss in yield was 159,260 t (5,851,000 bu), equivalent to 7% of the potential yield. Based on the 1977-1978 crop year returns to the producer and averaged for the six grades of wheat involved, the loss in value was $17,130,000.

**Effect of BYDV on Neepawa, Sinton, and Glenlea inoculated at four growth stages.** Seed yield losses indicated that Glenlea was the most affected by the virus and Neepawa was the least (Fig. 4). With Glenlea, the reduction in seed yield, 1,000 kernel weight, and number of seeds per plant was, with one exception, progressively less with inoculation at advanced growth stages (Fig. 4, Table 7). But Neepawa and Sinton showed a different trend; values for these characteristics were usually higher when plants were inoculated 45 days after seeding than at 38 days (Fig. 4, Table 7).

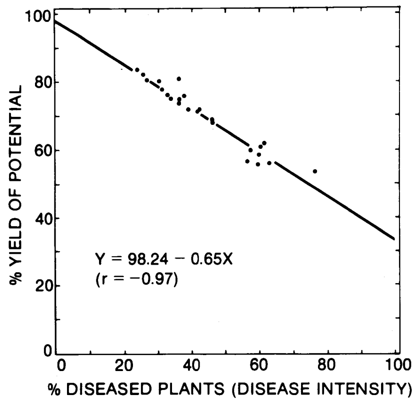


**Fig. 3.** Regression of the percent of diseased plants on the percent potential yield for Neepawa spring wheat, sampled in a grower's field naturally infected with barley yellow dwarf virus.

Other growth characteristics of the three cultivars, such as height, dry weight, number of culms, number and length of heads, and number of seeds per plant, usually showed progressively less reduction

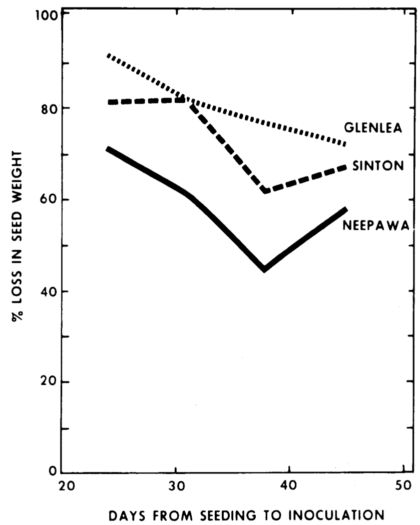


**Fig. 4.** Relationship between the percent loss in seed weight and the growth stage at which three spring wheat cultivars were inoculated with aphid-nonspecific isolate 7410 of barley yellow dwarf virus. Inoculation significantly reduced the total seed weight per plant ($P < 0.01$). The data does not, however, reject the hypothesis of equal loss for inoculation at each of the four growth stages.

**Table 5.** Germination test of seed[a] from healthy and barley yellow dwarf virus-infected wheat cultivars

| Cultivar | Germination of seed (%) | Mean weight of resultant seedlings[b] (g) | Reduction in seedling weight (%) |
|---|---|---|---|
| Neepawa | | | |
| Healthy | 88 | 0.69 | ... |
| Diseased | 78 | 0.53 | 23 |
| Glenlea | | | |
| Healthy | 93 | 1.00 | ... |
| Stunted[c] | 87 | 0.72 | 28 |
| Severely stunted[c] | 85 | 0.78 | 22 |

[a] 100 seeds per category.
[b] Aboveground parts were weighed immediately after cutting, 27 days after seeding.
[c] Severely stunted plants were 75 cm tall or less; stunted plants were more than 75 cm tall.

**Table 6.** Effect of barley yellow dwarf virus on milling properties of Neepawa and Glenlea spring wheats

| Property | Neepawa | | Glenlea | |
|---|---|---|---|---|
| | Healthy | Diseased | Healthy | Diseased (stunted)[a] |
| Grinding time (min) | 0.46 | 0.42 | 0.48 | 0.47 |
| Wheat protein (%) | 14.2 | 16.2 | 18.1 | 19.1 |
| Flour protein (%) | 13.6 | 15.7 | 12.0 | 15.7 |
| Flour yield (%) | 70.6 | 67.7 | 67.4 | 61.8 |
| Mixograph development time (min) | 2.0 | 1.8 | 7.0 | 6.5 |
| Sedimentation value (ml) | 48 | 53 | 52 | 65 |
| Falling number (sec) | 488 | 563 | 343 | 368 |

[a] Stunted plants were more than 75 cm tall, in contrast to severely stunted plants that were 75 cm tall or less. Seed of severely stunted plants was not tested.

Table 7. Effect of barley yellow dwarf virus isolate 7410[a] on yield components of three wheat cultivars inoculated at four growth stages

| Cultivar | Stage of inoculation[b] (Feekes' scale) | Mean percent reduction per infected plant[c] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Height | Dry weight | No. of culms | No. of heads | Length of heads | No. of seeds | 1,000 kernel weight |
| Neepawa | 3 | 29 | 63 | 27 | 26 | 14 | 59 | 36 |
| | 5 | 13 | 59 | 22 | 22 | 14 | 34 | 35 |
| | 7 | 15 | 34 | 8 | 8 | 4 | 23 | 27 |
| | 9 | 9 | 32 | 0 | 0 | 5 | 35 | 35 |
| Sinton | 3 | 23 | 73 | 37 | 42 | 23 | 64 | 43 |
| | 5 | 21 | 71 | 38 | 45 | 12 | 64 | 53 |
| | 7 | 15 | 51 | 23 | 26 | 8 | 48 | 23 |
| | 9 | 11 | 49 | 16 | 30 | 10 | 51 | 33 |
| Glenlea | 3 | 30 | 87 | 44 | 56 | 25 | 80 | 59 |
| | 5 | 27 | 77 | 28 | 45 | 23 | 63 | 47 |
| | 7 | 22 | 70 | 32 | 33 | 14 | 58 | 43 |
| | 9 | 6 | 48 | 0 | 18 | 9 | 51 | 43 |

[a] Aphid-nonspecific.
[b] Feekes' growth stages 3, 5, 7, and 9 may be interpreted approximately as early tillering, late tillering, early jointing, and late jointing, respectively (6).
[c] Compared with uninoculated plants.

with inoculation at advanced growth stages (Table 7).

Incipient symptoms on leaves of inoculated plants consisted of mild dark and light green mottling or banding, with varying degrees of chlorosis. These symptoms were followed within a day or two by the onset of yellow discoloration, particularly after inoculation at the two latest growth stages. After inoculation at the fourth growth stage, leaf yellowing was very pronounced and occurred on the uppermost one or two leaves per culm (sixth and seventh leaves on the main culm). The time of initial symptom appearance after inoculation increased from an average of 14.7 days for the earliest inoculation to 19.5 days for the last inoculation. Yellowed leaves died back prematurely from the tips during the stages of head emergence to anthesis. Seed from infected plants was shriveled and smaller than seed from healthy plants.

## DISCUSSION

The 1978 epidemic of BYD in spring wheat was caused by a large area of late-seeded crops, early infestation of these crops by aphid vectors, rapid secondary spread within fields from a small proportion of primarily infected plants, and predominance of the severe, aphid-nonspecific variant of BYDV. Spread of the virus was stimulated by moderately large populations of both *R. padi*, the most efficient vector of the variant, and *S. avenae,* the next most efficient vector.

The rapidity of secondary spread was possibly also influenced by a low population of predators and absence of heavy rains. An earlier than usual and rather rapid decline in these aphid populations prevented further spread of the disease near the end of the season and allowed ample time for symptoms to develop on infected plants before marking healthy and diseased plants of Neepawa and Glenlea in the field trials.

The loss estimations on Glenlea were not influenced by other diseases, but late infection of Neepawa by leaf rust, *Puccinia recondita* Rob. ex. Desm. may have decreased yield somewhat on plants not infected with BYDV. The yellowed leaves of BYDV-infected plants were not susceptible to the rust.

The estimated total loss on bread wheat of 159,260 t, omits possible losses that may also have occurred from the virus on Napayo and Norquay. These two cultivars, which have not yet been tested for their susceptibility to BYDV, accounted for 7% of the total production of wheat in the nine CRDs affected by the epidemic. Surveys of late-seeded oats and barley indicated that losses from the epidemic on these crops were probably also high.

It seems reasonable to suppose that virus would spread most rapidly in the field just before and during the period of peak aphid populations. Glenlea was in the late jointing stage at this peak period. The loss of 72% per plant, after inoculation at the same growth stage in the greenhouse trial, agreed well with the mean estimated loss of 73% per plant in the field.

The field of Neepawa was seeded about 3 wk earlier than the field of Glenlea. Neepawa was therefore at a more advanced growth stage (heading to anthesis) than Glenlea was when aphid populations were at peak numbers. The loss of 58% in the greenhouse trial with Neepawa inoculated at the late jointing stage was less than the mean estimated loss of 69% in the field. However, both Neepawa and Sinton showed greater losses when inoculated at the late jointing stage than at the early jointing stage. It is therefore possible that inoculation during the heading to anthesis stages could have had even more severe effects on the yield losses with these two cultivars. A higher yield loss on wheat with a late inoculation than with an early inoculation has been reported (10). Severe yellowing and premature dieback of the upper leaves on late infected wheat during anthesis and early ripening stages in the field and the greenhouse strongly suggested that these upper leaves would have little if any nutrients available for transport to the heads and for filling of kernels. These observations were strongly supported by the pronounced increase in the proportion of small, shriveled kernels from infected plants. The alteration in milling properties of the grain, the lower percent germination, and the poor vigor of plants grown from seed of diseased plants further reflected the effect of the disease on the metabolism of the plant and on the quality of the seed. Effects on the wheat protein content, flour yield, and sedimentation value were similar on grain from winter wheat infected with wheat streak mosaic virus (1).

The comparative genetic similarity between Sinton and Neepawa and the greater genetic differences between these two cultivars and Glenlea may account for the different trends in yield losses in the greenhouse trial for Sinton and Neepawa and for Glenlea.

The high degree of correlation between yield and the incidence of disease with Neepawa in the field trial suggests that yield losses from BYDV can be quantitated according to regression formulas. These results also indicate that no compensation occurred between healthy and diseased plants in the field. This was supported by visual examination in the field where diseased plants occurred in circular areas, with the most stunted in the center and progressively less stunting toward the healthy plants at the periphery.


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