Effects of Barley Yellow Dwarf Virus on Growth and Yield of Small Grains in Montana

D. J. YOUNT, Former Graduate Research Assistant, Department of Plant Pathology, J. M. MARTIN, Associate Professor, Department of Plant and Soil Science, and T. W. CARROLL, Professor, and S. K. ZASKE, Laboratory Technician, Department of Plant Pathology, Montana State University, Bozeman 59717

ABSTRACT

Yount, D. J., Martin, J. M., Carroll, T. W., and Zaske, S. K. 1985. Effects of barley yellow dwarf virus on growth and yield of small grains in Montana. Plant Disease 69:487-491.

Replicated field trials were conducted to determine the effects of barley yellow dwarf virus (BYDV) on the growth and yield of small grains in Montana. A vector-nonspecific isolate (MT-PAV) of the virus was used to infect six cultivars each of spring barley and spring wheat and five cultivars of winter wheat. Fifteen of these cultivars represented those commercially seeded to most of the wheat and barley acreage in central Montana from 1978 to 1981. One cultivar of spring barley (Sutter) and another of spring wheat (Anza), each previously reported resistant to the disease caused by BYDV, were included for comparison. *Rhopalosiphum padi* served as the aphid vector species for the inoculation trials. MT-PAV was highly virulent in all Montana small grains tested. On the basis of symptom expression, growth characteristics, and yield factors, all Montana small-grain cultivars were classified as susceptible to the virus disease and intolerant (sensitive) to the virus. When infected plants were compared with uninoculated control plants, the mean reduction in grain yield for the susceptible Montana cultivars was 44.7% for two-rowed barleys, 65.1% for six-rowed barleys, 74.5% for spring wheats, and 67.1% for winter wheats. The mean reduction in 1,000-seed weight was 35.2% for two-rowed barleys, 28.5% for six-rowed barleys, 40.4% for spring wheats, and only 9.6% for winter wheats.

In 1959, barley yellow dwarf (BYD) was diagnosed in Montana (13). It occurred mainly in spring barley but was also present in spring oats in localized areas. Most crop damage was present in fields planted in June. Because corn leaf aphids (*Rhopalosiphum maidis* (Fitch)) were found in diseased barley fields, they were presumed to be vectors of the causal virus. However, adjoining fields of wheat and oats often lacked these aphids and appeared to be nondiseased. For the next 20 yr, BYD was considered a disease of only minor importance in Montana spring barley and oats.

In 1980 and 1981, BYD was epidemic in winter wheat fields in central Montana (20). In the early spring of those years, diseased plants showed discoloration and dwarfing symptoms formerly attributed to nitrogen deficiency or cold, water-saturated soil. By late spring each year, however, these plants expressed the usual leaf discoloration and the dwarfing symptoms described for BYD in susceptible wheats grown in environments optimal for the disease (19). The most prevalent isolate of BYDV (BYD luteovirus) recovered from those diseased wheat fields both years was vector-nonspecific (20). This field isolate was designated Montana PAV (MT-PAV) because it was vectored by either *R. padi* (L.) or *Macrosiphum* (*Sitobion*) *avenae* (Fabricius) with similar levels of transmission efficiency. It was highly virulent in wheat, barley, and oats. Identification of the isolate was made by aphid transmission tests and enzyme immunosorbent assays (EIA). Also present in Montana at this time were *R. maidis* and BYDV isolates (RMV-like isolates) vectored specifically by this aphid species (20). Most of these RMV-like isolates were obtained from viruliferous *R. maidis* collected in spring barley fields. They were only mildly virulent in indicator test plants of barley, oats, and wheat, as determined by aphid transmission tests. On the basis of this recent information to interpret the BYD situation in Montana in 1959, we believe the earlier disease was caused mainly by one or more RMV-like isolates of BYDV.

In an attempt to determine the effects of the virulent MT-PAV, BYDV, on plant growth and seed yield under Montana conditions, replicated field trials were conducted with winter wheat, spring barley, and spring wheat. Leading cultivars grown commercially in central Montana between 1978 and 1981 and two cultivars shown resistant to BYD were tested. Results of the trials were to be used to classify each cultivar as resistant or susceptible to BYD disease or as tolerant or intolerant to MT-PAV. For the purpose of this paper, disease resistance or susceptibility refer to the extent to which each cultivar was vulnerable to infection by MT-PAV (i.e., suffered growth and yield loss). By comparison, tolerance or intolerance refer to degree of symptom severity with which the host responded to the virus infection as judged by the amount and intensity of foliar discoloration and the extent of dwarfing. These terms coincide with those reported by Bos (1).

Published with the approval of the director as Journal Series Paper 1538, Montana Agricultural Experiment Station.

Portion of a thesis submitted by the first author in partial fulfillment of requirements for the M.S. degree.

This work was partially supported by Contract No. AID/DSAN-C0024, Agency for International Development, Department of State, Washington, DC.

Accepted for publication 17 December 1984 (submitted for electronic processing).

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be hereby marked *"advertisement"* in accordance with 18 U.S.C. § 1734 solely to indicate this fact.

MATERIALS AND METHODS

The effects of BYDV infection on yield and yield components of barley (*Hordeum vulgare* (L.)), spring wheat (*Triticum aestivum* (L.)), and winter wheat (*T. aestivum* (L.)) cultivars were evaluated over a period of two crop years. Experimental plots were located at the Arthur H. Post Field Research Laboratory near Bozeman, MT. The field experiments consisted of healthy control and diseased plots for each cultivar. The small-grain cultivars used in those field experiments, including the resistant spring barley, Sutter (11), and the resistant spring wheat, Anza (10,) are listed in Table 1.

Diseased plots were artificially inoculated with a vector-nonspecific isolate (MT 792, a PAV isolate) of BYDV (19) and the oat, bird-cherry aphid (*R. padi*) was used as the vector species. Viruliferous aphids were reared on infected Coast Black oats (*Avena byzantina* (Koch)) or Klages barley in a growth chamber maintained at 21 C under continuous fluorescent and incandescent light (about 10,000 lux) and about 40% relative humidity. At the end of each 4- to 5-wk rearing period, aphids were removed from the virus source plants and placed in plastic dishes for transport to the field. Talc powder was sprinkled over the aphids to assist in their dissemination, which was accomplished by spreading viruliferous aphids evenly over each row in a diseased plot. At least five aphids were deposited per plant. After a 5-day inoculation period, both the diseased and healthy plots were sprayed with dimethoate (Cygon 400) to kill aphids and prevent secondary spread of the virus. Thereafter, all plots were sprayed periodically with malathion to minimize aphid transmission of the virus within plots.

In both 1980 and 1981, six cultivars of spring barley (Tables 1 and 2) and six cultivars of spring wheat (Tables 1 and 3) were planted in separate experiments. Each experiment was planted in two replications of a randomized block, split-plot design with control and BYDV-inoculated treatments as main plots and cultivars as subplots. Two 3-m long rows of each cultivar were planted 35 cm apart within each main plot. Main plots were separated by 1.2-m alleys. Barley was planted on 12 May 1980, and viruliferous aphids were placed on the plants when they were in the first tiller formation stage of development (Feekes stage 2) (6). The 1981 barley trial was planted on 21 May and inoculated with viruliferous aphids when the seedlings were in the second tiller formation stage of development (Feekes stage 3). Because of a shortage of viruliferous aphids in 1981, only one of the two spring barley replicates was inoculated. The spring wheat trials were planted on 2 May 1980 and on 22 April 1981. Viruliferous aphids were applied when plants were in the five-leaf stage of development (Feekes stage 3) during both years.

In the 1980 and 1981 crop years, five winter wheat cultivars (Tables 1 and 4) were planted in a control and an adjacent inoculated block. In 1980, each of the five cultivars was replicated three times within each block and randomized as single 2-m rows spaced 35 cm apart. In 1981, each of the five cultivars was planted as four 3-m rows spaced 35 cm apart, with cultivars randomized in each of two blocks. The two experiments were planted on 12 September 1979 and 10 September 1980. Viruliferous aphids were applied when seedlings were in the three-leaf stage of development (Feekes stage 2) during both years.

Symptoms of BYD were recorded during both years for all cultivars. Cultivars in the control plots were also checked for BYD symptoms in the event that any applied vectors, their progeny, or naturally occurring field vectors had introduced virus into the plots. The spring-planted grains were read for symptoms at about 2 wk intervals until ripening (Feekes stage 11). Symptom development in the fall-seeded winter wheat was noted 17 days after the viruliferous aphids were applied. Subsequent readings were made at biweekly intervals until mid-December. Symptom recording of the winter wheat was resumed the following May on a biweekly basis until the plants reached the mealy-ripe stage of development (Feekes stage 11).

In the 1980 and 1981 spring barley and spring wheat trials, data were obtained from 15 individual plants randomly selected from the center 2 m of each plot row. In the 1980 winter wheat trial, 15 individual plants were randomly selected from the center 1.5 m of each plot row, whereas in 1981, individual plants were randomly selected from only the two center rows of each four-row plot. Data collected included grain yield, 1,000-seed weight, tillers per plant, seeds per head from the central tiller, and plant height.

Table 1. Small-grain cultivars used in 1980 and 1981 field experiments to measure effects of barley yellow dwarf virus on growth and yield

Cultivar	Identification no.	Background
Winter wheats		
Warrior	CI 13190	Pawnee × Cheyenne
Winoka	CI 14000	Selection from Winalta
Winalta	CI 13670	Minter × Wichita
Cheyenne	CI 8885	Selection from Crimean CI 1435
Centurk	CI 15075	Kenya 58/2/Newthatch/3/Hope/2*Turkey/Cheyenne/5/Parker
Spring wheats		
Fortuna	CI 13596	Rescue × Chinook × (Frontana × Kenya 58-Newthatch)
Lew	CI 17429	Fortuna/S6285
Olaf	CI 15930	Waldron/selection from Justin × Conley × Norin 10
Tioga	CI 17286	Fortuna/S6285
Prodax	CI 17407	Tezanos Pinto Precoz/Sonora 64/3/Lerma Rojo 64/Tezanos Pinto Precoz/Andes Dwarf/4/2* Jaral//Mengavi/8156
Anza	CI 15284	(Lerma Rojo × Norin₃ 10-Brevon) × Andes[3]
Spring barleys		
Two-row		
Hector	CI 15514	Betzes × Pallister
Klages	CI 15478	Betzes × Domen
Compana	CI 5438	Selection from CI 4116
Six-row		
Steptoe	CI 15229	Washington 3564 × Unitan
Unitan	CI 10421	Glacier × Titan
Sutter	CI 15475	Selection from CI 1237 × Winter Tennessee

Table 2. Effects of infection of a barley yellow dwarf virus isolate (MT-PAV) on growth and yield of six barley cultivars in Montana during 1980 and 1981[a]

	Plant height (cm)		Tillers/plant		Seeds/head		1,000-seed wt (g)		Yield (g/plant)	
Cultivar	Cont.[b]	Inoc.[c]	Cont.	Inoc.	Cont.	Inoc.	Cont.	Inoc.	Cont.	Inoc.
Hector	74.4	58.9**[d]	6.0	3.8**	24.1	19.1**	42.3	29.3**	29.6	7.9**
Klages	72.1	52.3**	5.9	3.8**	24.7	20.7*	42.7	27.1**	33.3	8.9**
Compana	68.1	57.0**	6.1	4.1**	19.9	16.7	54.9	34.1**	32.6	10.8**
Unitan	73.3	60.0**	3.6	2.8	44.2	34.1**	42.4	30.3**	40.4	11.6**
Steptoe	69.8	56.3**	3.3	2.9	48.9	36.5**	45.1	32.3**	34.6	14.5**
Sutter	72.4	68.7	4.2	4.5	44.6	46.9	35.5	36.9	32.5	35.9
Mean	71.7	58.8**	4.9	3.7**	34.4	29.0**	43.8	31.7**	33.8	14.9**
LSD (0.05)[d]	NS	6.8	1.1	NS	4.1	3.8	3.4	NS	6.1	14.8

[a]Average of two replicates in 1980 and one replicate in 1981.
[b]Control.
[c]Inoculated.
[d]LSD = least significant difference between cultivars within a given treatment, control or inoculated. Differences between control and inoculated means are significantly greater than 0.0 at * = $P = 0.05$ and ** = $P = 0.01$.

The effect of BYDV was measured as the difference between the control and the corresponding inoculated plot for each replicate. These difference values were subjected to conventional analysis of variance, and mean separation tests were performed using least significant difference (15). Because experimental procedures differed slightly in both years and because year × cultivar interaction was significant in many instances, data were not combined over years for spring and winter wheat trials. Inasmuch as only one replicate was inoculated in the 1981 barley trial, the two replicates in 1980 and one in 1981 were treated as three replicates of a single experiment.

RESULTS AND DISCUSSION

On the basis of symptom severity (leaf discoloration and dwarfing) or yield loss (reduction in grain number and seed weight), all cereal-grain cultivars tested except Sutter were classified as intolerant to MT-PAV, BYDV, or susceptible to the disease caused by that virus, respectively. For the purpose of comparison, these cultivars were classified according to a visual disease or symptom rating scale for each of the three kinds of cereal-grain crops investigated. All spring barleys except Sutter were classified as type 3 (extensive discoloration and moderate dwarfing) by the rating system of Schaller et al (12). All spring wheats including Anza were classified as types 5–8 (extensive yellowing, moderate to severe dwarfing, and reduced spike size) following the scoring system of Topcu (17). All winter wheats were classified as types 5–7 on the symptom scale (0 = no symptoms to 9 = conspicuous chlorosis,

Table 3. Effects of infection of a barley yellow dwarf virus isolate (MT-PAV) on growth and yield of six spring wheat cultivars in Montana during 1980 and 1981

	Plant height (cm)		Tillers/plant		Seeds/head		1,000-seed wt (g)		Yield (g/plant)	
Cultivar	Cont.[a]	Inoc.[b]	Cont.	Inoc.	Cont.	Inoc.	Cont.	Inoc.	Cont.	Inoc.
1980										
Fortuna	103.8	77.0**[c]	9.0	7.5*	28.2	20.2**	42.8	25.8**	7.8	2.5**
Tioga	103.5	79.8**	8.8	7.8*	28.5	20.8**	37.9	23.5**	7.1	2.4**
Lew	103.4	74.1**	9.2	7.5**	31.0	20.8**	31.8	21.8**	6.5	2.0**
Olaf	81.7	67.6**	7.2	6.2*	32.8	26.8**	33.6	26.8**	6.8	2.9**
Prodax	80.4	62.0**	7.0	5.5*	51.8	36.2**	34.4	19.9**	6.5	2.3**
Anza	74.7	64.0**	7.8	7.3	41.8	37.0**	32.3	23.4**	7.2	4.0*
Mean	91.4	70.8**	8.2	7.0**	35.7	27.0**	35.4	23.6**	7.1	2.6**
LSD (0.05)[c]	8.0	6.7	1.3	1.1	2.3	3.8	4.3	NS	NS	0.2
1981										
Fortuna	102.4	85.0**	2.8	2.0**	31.9	23.0**	43.2	23.4**	3.2	0.9**
Tioga	101.9	80.8**	2.5	2.0**	30.3	24.5*	36.4	23.6**	2.0	1.0*
Lew	99.7	78.4**	2.4	1.4**	35.3	22.1**	37.4	20.8**	2.5	0.6**
Olaf	83.8	68.7**	2.2	2.1	35.9	24.4**	34.6	20.0**	2.2	0.9**
Prodax	80.7	64.8**	2.3	1.6**	49.0	30.2**	39.0	14.5**	3.2	0.6**
Anza	71.4	62.6**	1.8	1.8	42.4	33.0**	33.4	23.4**	2.1	1.1*
Mean	89.9	73.5**	2.3	1.8**	37.5	26.2**	37.3	21.0**	2.6	0.9**
LSD (0.05)	4.9	5.9	NS	NS	4.1	4.1	3.3	5.5	1.0	NS

[a] Control.
[b] Inoculated.
[c] LSD = least significant difference between cultivars within a given treatment, control or inoculated. Differences between control and inoculated means are significantly greater than 0.0 at * = $P = 0.05$ and ** = $P = 0.01$.

Table 4. Effects of infection of a barley yellow dwarf virus isolate (MT-PAV) on growth and yield of five winter wheat cultivars in Montana during 1980 and 1981

	Plant height (cm)		Tillers/plant		Seeds/head		1,000-seed wt (g)		Yield (g/plant)	
Cultivar	Cont.[a]	Inoc.[b]	Cont.	Inoc.	Cont.	Inoc.	Cont.	Inoc.	Cont.	Inoc.
1980										
Centurk	114.9	88.3**[c]	12.0	8.0**	41.7	28.3**	32.4	30.1**	10.5	4.9**
Warrior	124.0	91.1**	11.7	8.3**	35.3	21.7**	34.6	31.4**	9.8	3.7**
Winoka	128.8	91.7**	12.3	6.3**	36.7	20.7**	35.2	29.3**	11.8	2.6**
Winalta	130.2	91.3**	9.0	7.3	35.7	20.0**	35.0	29.4**	8.2	2.8**
Cheyenne	119.5	86.2**	12.3	7.3**	38.7	19.3**	36.7	31.2**	12.0	3.3**
Mean	123.5	89.8**	11.5	7.5**	37.6	22.0**	34.8	30.3**	10.5	3.5**
LSD (0.05)[c]	5.7	NS	2.3	NS	3.4	2.8	2.3	NS	NS	NS
1981										
Centurk	132.6	98.0**	11.8	7.2**	45.9	30.1**	31.8	32.7	11.6	4.6**
Warrior	140.5	108.4**	10.6	4.9**	35.5	13.1**	31.8	29.2	5.7	1.5**
Winoka	147.3	99.1**	10.0	5.0**	28.1	14.4**	31.8	28.0	5.3	1.6**
Winalta	144.6	102.9**	10.4	5.8**	29.4	16.6**	32.6	30.3	5.4	1.6**
Cheyenne	134.9	107.0**	11.1	5.4**	26.0	14.4**	31.8	29.6	3.8	1.4**
Mean	140.0	103.1**	10.8	5.7**	33.1	17.7**	32.0	30.0*	6.4	2.1**
LSD (0.05)	6.5	6.8	0.9	0.9	5.0	2.1	NS	NS	1.1	0.6

[a] Control.
[b] Inoculated.
[c] LSD = least significant difference between cultivars within a given treatment, control or inoculated. Differences between control and inoculated means are significantly greater than 0.0 at * = $P = 0.05$ and ** = $P = 0.01$.

necrosis, and severe dwarfing) of Carrigan et al (2).

The disease symptoms for barley observed in this study were similar to those described for BYD by Mathre (7). In both 1980 and 1981, symptoms appeared in the disease plots about 17 days after inoculation. Infection was uniform throughout the inoculated plots in both years, with virtually all plants becoming infected. The uninoculated plots remained symtomless except for a few scattered plants in border rows. All cultivars of spring barley showed strong leaf yellowing and dwarfing symptoms. A few plants of the resistant cultivar Sutter showed some slight yellow discoloration compared with symptomless controls. That Sutter was infected was confirmed by aphid transmission experiments. In both years, all barley cultivars including Sutter were dwarfed compared with the uninoculated controls (Table 2). Growth of the cultivar Klages in both years was affected to the extent that heads seldom emerged from the boot and some plants developed into rosettes.

Grain yield, 1,000-seed weight, and plant height were significantly reduced for all cultivars except Sutter in both years (Table 2). Tiller production was significantly reduced in the susceptible and intolerant two-rowed cultivars Hector, Klages, and Compana (Table 2). The average reduction in grain yield and 1,000-seed weight was 44.7 and 35.2% for two-rowed barleys and 65.1 and 28.5% for six-rowed barleys, respectively. Yield reductions of 39% (18) and 70% (16) were reported in commercial cultivars of spring barley more than 20 yr ago. In contrast, Sutter (11) was found to be tolerant to MT-PAV, BYDV, and resistant to the disease caused by that virus because it suffered no significant reduction for any measured trait (Table 2). Infected Sutter yielded 10.5% more grain with a 3.9% higher 1,000-seed weight than did the uninoculated Sutter control. The small increases for Sutter in inoculated over control plots probably reflected a competitive advantage for a tolerant genotype growing adjacent to genotypes severely affected by the disease.

In the 1980 and 1981 spring wheat experiments, all plants in the diseased plots became infected. In both years, the uninoculated plots remained healthy except for a few plants in border rows in the 1980 plots. However, enough healthy plants were noted and tagged in these rows for valid comparisons to be made. All of the Montana cultivars of spring wheat displayed severe leaf symptoms of BYD. Symptoms were first observed about 15 days after inoculation in 1980 and 1981 as leaf tip chlorosis. Leaves that first showed symptoms eventually became totally yellow and prematurely senescent compared with healthy leaves. Newly emerged leaves first developed leaf tip chlorosis followed by marginal and interveinal yellowing extending about one-half to two-thirds of the way down the leaf blade, giving a chevron pattern appearance. Later, some cultivars, such as Olaf, developed red and purple leaves. In Anza, symptom development lagged about 4–5 days behind that of susceptible cultivars. Symptoms were not as severe in Anza, being limited primarily to leaf tip and leaf margin chlorosis. Plant stunting was significant in all cultivars for both test years, although Anza was least affected in this regard (Table 3). The tall cultivars Fortuna, Tioga, and Lew were more dwarfed by the virus than were the semidwarf cultivars Olaf and Prodax.

Grain yield was significantly reduced in all spring wheat cultivars in both years (Table 3). Although differences between control and inoculated yields were considerably larger in 1980 than in 1981, average percentage yield reductions were similar in both years. The spring wheats had an average yield reduction of 74.5% and an average 1,000-seed weight reduction of 40.4% relative to the controls over both years tested. Anza suffered a yield reduction of 44.7% and a 1,000-seed weight reduction of 28.9%. In England, the yield of spring wheat was lowered 36% (18) when a virulent isolate of BYDV was used to inoculate field plots. Grain yields of the spring wheat cultivar Olympic decreased 9–79% in artificially inoculated plots at three sites in Australia (14).

Symptoms in the inoculated winter wheat plots for both 1980 and 1981 experiments did not appear until growth resumed in the spring. Infected plants were mildly chlorotic and dwarfed compared with healthy plants. Prior to stem elongation, tip chlorosis and chlorotic mottle symptoms became visible in leaves that had emerged the previous fall and in the first leaves developed in the spring. These leaves eventually became totally yellow and prematurely senescent compared with leaves of healthy plants. Newly emerged leaves, including the flag leaves, developed leaf tip chlorosis, marginal chlorosis, and a chlorotic mottle, much more so than in spring wheats. Anthocyanin pigmentation was extensive in the cultivars Warrior, Winoka, and Cheyenne, where leaves completely changed to red-scarlet. Very little interveinal chlorosis was observed in the winter wheats compared with the spring wheats. Also, leaves of diseased winter wheat plants were short and narrow, slightly cupped abaxially, and spikelike, whereas leaves of healthy plants were long, wide, and tended to bend downward from the culm. More significant dwarfing occurred in winter wheat cultivars both years (Table 4) than in spring wheat or spring barley cultivars.

Grain yield was significantly reduced in inoculated compared with control plots for all five winter wheat cultivars in both years (Table 4). Reports in the literature on the effect of BYDV on grain yield of fall-inoculated winter wheat give reductions of 26–60% in Kansas (8), 81% for Winalta in South Dakota (5), 31% in England (4), 33 and 58% in Indiana (2), and 63% in Illinois (3). In our study, grain yield reduction for the five winter wheat cultivars averaged 67.1%, which is similar to the other yield loss reports. However, the 1,000 seed weight, averaged over cultivars and years, was not reduced appreciably (9.6%). Centurk, though intolerant to MT-PAV, did show the least amount of yield loss over both years tested, indicating that it was less susceptible than the other cultivars to BYD. Cisar et al (3) reported Centurk as a tolerant parent in studies of tolerance to a vector-nonspecific isolate of BYDV in winter wheat.

The results of the barley, spring wheat, and winter wheat trials cannot be compared directly because each kind of grain crop was grown as a separate experiment. Average percentage yield reductions, however, were remarkably similar from year to year and across the three cereal grains. None of the yield components suffered as much percentage loss as grain yield. This was in part because seeds per head were measured from only the central tiller of each plant and because light seeds from diseased plants may have been lost during threshing.

Determinations of crop losses for the Montana cultivars of spring barley, spring wheat, and winter wheat experimentally infected with the MT-PAV-virulent isolate of BYDV will allow us to estimate more accurately the losses in Montana caused by natural infection by BYDV in those crops. Experimental plot determinations can be related to such pertinent field data as virus isolate or isolates involved, plant growth stage at the time of infection, aphid effects, and environmental factors (9).

ACKNOWLEDGMENTS

We thank Gene Holland, Heather Merrideth, Wayne Fjelstad, and Sherri Johnson for technical assistance with portions of this study.

LITERATURE CITED

1. Bos, L. 1983. Introduction to Plant Virology. Longman Inc., New York. 160 pp.
2. Carrigan, L. L., Ohm, H. W., Foster, J. E., and Patterson, F. L. 1981. Response of winter wheat cultivars to barley yellow dwarf virus infection. Crop Sci. 21:377-380.
3. Cisar, G., Brown, C. M., and Jedlinski, H. 1982. Effect of fall or spring infection and sources of tolerance of barley yellow dwarf of winter wheat. Crop Sci. 22:474-478.
4. Doodson, J. K., and Saunders, P. J. W. 1970. Some effects of barley yellow dwarf virus on spring and winter cereals in field trials. Ann. Appl. Biol. 66:361-374.
5. Fitzgerald, P. J., and Stoner, W. N. 1967. Barley yellow dwarf studies in wheat (*Triticum aestivum* L.) I. Yield and quality of hard red winter wheat infected with barley yellow dwarf virus. Crop Sci. 7:337-341.
6. Large, E. C. 1954. Growth stages in cereals.

Illustrations of the Feekes' scale. Plant Pathol. 3:128-129.
7. Mathre, D. E. 1982. Compendium of Barley Diseases. American Phytopathological Society, St. Paul, MN. 78 pp.
8. Palmer, L. T., and Sill, W. H. 1966. Effect of barley yellow dwarf virus on wheat in Kansas. Plant Dis. Rep. 50:234-238.
9. Plumb, R. T. 1983. Barley yellow dwarf virus—a global problem. Pages 185-198 in: Plant Virus Epidemiology. The Spread and Control of Insect-Borne Viruses. R. T. Plumb and J. M. Thresh, eds. Blackwell Scientific Publications, Boston. 377 pp.
10. Qualset, C. O., Prato, J. D., Rupert, J. A., Vogt, H. E., Khalifa, M. A., Lehman, W. F., and Isom, W. H. 1973. Anza—A new high-yielding short-statured wheat variety. Calif. Agric. 27:14-15.
11. Schaller, C. W., Prato, J. D., and Chim, C. I. 1973. Registration of Sutter barley. Crop Sci. 13:285.
12. Schaller, C. W., Rasmusson, D. C., and Qualset, C. O. 1963. Sources of resistance to the yellow-dwarf virus in barley. Crop Sci. 3:342-344.
13. Sharp, E. L. 1959. Yellow dwarf virus in Montana in 1959. Plant Dis. Rep. Suppl. 262:355.
14. Smith, P. R., and Sward, R. J. 1982. Crop loss assessment studies on the effects of barley yellow dwarf virus in wheat in Victoria. Aust. J. Agric. Res. 33:179-185.
15. Snedecor, G. W., and Cochran, W. G. 1980. Statistical Methods. 7th ed. Iowa State University Press, Ames. 507 pp.
16. Suneson, C. A., and Ramage, R. T. 1957. Studies on the importance of the yellow-dwarf virus. Agron. J. 49:365-367.
17. Topcu, M. A. 1975. The inheritance of resistance to the barley yellow dwarf virus in wheat (*Triticm aestivum* L.). Ph.D. dissertation. University of California, Davis. 127 pp.
18. Watson, M. A., and Mulligan, T. E. 1960. Comparison of two barley yellow-dwarf viruses in glasshouse and field experiments. Ann. Appl. Biol. 48:559-574.
19. Wiese, M. V. 1977. Compendium of Wheat Diseases. American Phytopathological Society, St. Paul, MN. 106 pp.
20. Yount, D. J., and Carroll, T. W. 1983. Barley yellow dwarf luteoviruses in Montana cereals. Plant Dis. 67:1217-1222.