The Effects of Planting Date and Insecticide Treatments on the Incidence of High Plains Disease in Corn

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ABSTRACT

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Incidence of High Plains Disease (HPD) in a susceptible corn cultivar was examined in relation to planting dates, insecticide treatments, and wheat heading dates during 1994 to 1996. In the High Plains of Texas, this disease of susceptible corn was related to corn planting dates and winter wheat maturity. The incidence of HPD varied greatly from year to year; however, corn planted between 16 and 20 May had the highest disease incidence. Corn planted 10 to 30 days after wheat heading had the highest incidence of the disease. Chemical control of the vector, *Aceria tosichella*, was ineffective, except by the use of granular insecticides applied at planting, which had some beneficial effects. Results of this study suggest that producers can reduce the incidence of HPD by planting corn before or after the peak migration of wheat curl mite from wheat.

Additional keywords: *Aceria tosichella*

In 1987, wheat streak mosaic virus (WSMV) was widespread throughout the Texas Panhandle and caused extreme losses. However, the disease seemed to behave differently than in previous "wheat-streak years"; entire fields of wheat were drying up and dying (C. M. Rush, *personal observation*). The severity of the problem was attributed to WSMV in combination with a variety of other stresses, such as freeze damage, drought, and herbicide damage. In 1993, this disease again caused extreme damage and entire fields of wheat were killed. As in 1987, disease severity and plant death were attributed to a combination of stresses. However, in 1993, severe disease also developed in corn. Infected plants had symptoms similar to wheat streak (stunting and mosaic) but, as in the wheat crop, infected corn plants were killed. In most instances, WSMV was detected in infected tissue but, due to the severity of the symptoms, a second pathogen was suspected (7,9). Farmers, industry personnel, and scientists began to question whether a new, highly virulent strain of WSMV had evolved that was capable of killing both corn and wheat. However, this proved not to be the case and, by the end of

1993, a new disease, designated High Plains Disease (HPD), had been described (7). The pathogen of this disease, named the high plains virus (HPV; 10), was detected in many areas throughout the Great Plains and Pacific Northwest, and was devastating to susceptible varieties of corn and wheat (8,15). It has not yet been completely purified or characterized. In Idaho, approximately 750 acres of sweet corn were affected by this disease, with yield losses exceeding 50% in some corn fields (3). HPD is associated with a 32-kDa protein of unknown origin but is likely a nucleoprotein rather than a capsid protein (10,11). The ultrastructure of infected cells resembles those infected with rose rosette, redbud yellow ringspot, fig mosaic, and thistle mosaic viruses (1). HPV can be identified using double-antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA) and Western Blot analysis (10,11).

Symptoms of HPD on infected wheat are similar to those caused by WSMV and include mottled, yellowed leaves, stunted growth, and often death (5). Infected corn plants have similar symptoms; a mosaic pattern on the leaves and, in advanced stages, streaks that run the length of the leaf. These turn reddish purple and eventually necrotic, so that the leaf may die. The stage at which plants are infected impacts severity of symptoms, with younger plants being more adversely affected. Typically, infected seedlings die.

The wheat curl mite, *Aceria tosichella* Keifer (2), which transmits WSMV (19), is also the vector of HPV (18). Some wheat and corn plants have been found to be infected with both viruses (7,8,10,15). The

presence of both of these viruses in wheat leads to severe chlorosis, stunting, and necrosis; however, it has not yet been determined if this is a synergistic effect, or if HPV alone can produce the same level of severity (11). In general, corn infected with WSMV displays few symptoms (12); however, susceptible corn plants infected with HPV have very distinct symptoms. The movement of mites from wheat to corn in early summer and, later, from corn to fall-planted winter wheat, promotes the spread of plant viruses (14). It was theorized that, in the spring, wheat curl mites from maturing, diseased wheat were windblown into cornfields where they transmitted the HPV to susceptible corn cultivars (13). When this study was initiated in 1994, it was important to quickly determine the epidemiology of the disease and find methods to decrease its incidence. In a previous study, the incidence of WSMV was reduced in wheat by using carbofuran, a systemic insecticide, to control wheat curl mite (4). Therefore, controlling the mite was one potential method of reducing the incidence of HPD in corn. Furthermore, it was observed that symptoms of HPD first appeared when plants were small, and symptom severity varied with time of infection (9,10). Therefore, planting dates were also hypothesized to have an effect on incidence and severity of the disease. The purpose of our study was to determine if planting dates and insecticide-acaricide applications for mite control would have a significant effect on the incidence of HPD in corn.

MATERIALS AND METHODS

Research was conducted in the summers of 1994 through 1996 at the Texas Agricultural Experiment Station, Bushland. Based on preliminary data from 1993, a susceptible and a resistant corn cultivar (Golden Harvest [GH] 2544 and 2530, respectively) were planted in 1994 and 1995 using a cone planter set at a 76.2-cm row spacing. Neither disease symptoms nor presence of the pathogen were found on GH 2530; therefore, only the susceptible cultivar, GH 2544, was planted in 1996. Planting dates each year were as follows: 15 April, 16 May, and 16 and 30 June 1994; 21 April, 18 May, and 15 and 28 June 1995; and 18 April, 20 May, and 20 June 1996. Chemical treatments for 1994 and 1995 consisted of one foliar application of carbofuran (Furadan 4F) applied at a rate of 1.12 kg AI/ha, two foliar

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applications of Furadan 4F at the same rate (with the second application made 1 week after the first), and an untreated check. Treatments for 1996 consisted of granular systemic insecticides-acaricides; phorate (Thimet 20G), terbufos (Counter 20CR), and disulfoton (Disyston 15G); and an untreated check. Each chemical treatment was incorporated into the soil at planting time at 1.12 kg AI/ha. Plots consisted of four rows, 8.23 m in length, and within a given planting date there were six replications of the cultivar $\times$ chemical treatment combination. An alley (3.05 m wide), kept clean of vegetation, separated blocks. Treatments within a planting date were arranged in a randomized, split-split-plot design with planting dates as the main plot, cultivars as subplots, and insecticide treatments as sub-subplots.

Percent disease incidence was determined on five dates in 1994, seven dates in 1995, and five dates in 1996. Evaluations consisted of counting all plants within a plot to obtain a stand count, then counting plants displaying typical diagnostic symptoms of HPD. Each year, a sample of symptomatic plants was collected and tested by DAS-ELISA to verify that symptoms were indeed those caused by the HPV. Counts were taken until corn began to senesce and disease symptoms could no longer be positively determined.

Heading dates for winter wheat, cv. TAM 107, in plots near the corn plantings were obtained from records maintained at the Texas Agricultural Experiment Station at Bushland. Heading dates for each year were averaged to determine if there was a correlation between the onset of wheat senescence, the percent HPD incidence, and planting dates of corn. Additionally, each corn planting date within a given year was ranked on a scale of 1 to 4, with 1 having the lowest cumulative incidence of infected plants and 4 having the highest.

Disease incidence data for sampling dates within a year were first tested for

normality by generating the Shapiro-Wilk W statistic available in the SAS univariate procedure (16). The dates were determined to be normally-distributed; therefore, they were subjected to analysis of variance without transformation (16). Significant means were separated using the Student-Newman-Keuls test ($P = 0.05$) available in the SAS GLM procedure (16).

Maximum percentage of HPD incidence rating (designated by scale ranking of 1 to 4) as a function of the average deviation (in days) from wheat heading to corn planting for all three years was analyzed as second-order polynomials. The correlation coefficient (r) for this polynomial was determined using standard statistical techniques (20).

RESULTS

Chemical control. The application of insecticides-acaricides to control mites had little effect on HPD incidence, or the results were too erratic to give a clear conclusion. In 1994, there were no significant

differences among untreated or treated corn plants receiving one or two foliar applications of Furadan 4F, regardless of planting date. In the 1995 (Table 1) first, second, and third plantings, at least one sampling date resulted in significant differences in percent HPD incidence among Furadan-treated and untreated corn. No significant differences were found at any sampling date in the fourth planting. When significance occurred, it usually indicated a significant decrease in the percent HPD incidence in treated versus untreated corn. There were no significant differences between one or two foliar Furadan applications.

In 1996 (Table 2), the application of Counter 15CR at planting time significantly reduced the percent HPD incidence in corn from the second planting-time plots at the first three samplings, and at one sampling date in corn from the third planting. No other treatments resulted in a significant reduction in percent HPD incidence from the untreated check in 1996.

Table 2. Percent disease incidence of treated and untreated corn plants with High Plains Disease on different planting dates in 1996

Treatment (date) ^z	% Disease incidence on sampling date ^y				
	18 June	2 July	16 July	29 July	12 August
First planting (18 April)					
untreated	0.15 a	0.07 a	0.05 a	...	...
Disyston 15G	0.20 a	0.11 a	0.03 a	...	...
Thimet 20G	0.25 a	0.08 a	0.07 a	...	...
Counter 20CR	0.13 a	0.09 a	0.05 a	...	...
Second planting (20 May)					
untreated	2.04 a	3.13 a	2.75 a	2.22 a	1.78 a
Disyston 15G	1.96 a	2.97 a	2.69 a	2.46 a	1.46 a
Thimet 20G	2.03 a	2.68 a	2.37 a	1.99 a	1.40 a
Counter 20CR	1.12 b	1.96 b	1.57 b	1.54 a	1.11 a
Third planting (20 June)					
untreated	...	0.02 a	2.34 a	0.03 a	0.02 a
Disyston 15G	...	0.00 a	2.30 a	0.03 a	0.00 a
Thimet 20G	...	0.00 a	1.97 a	0.07 a	0.07 a
Counter 20CR	...	0.02 a	1.28 b	0.02 a	0.00 a

^y Means in a column, with planting dates, followed by the same letter are not significantly different ($\alpha = 0.05$; Student-Newman-Keuls test).

^z All treatments applied in furrows at planting time at a rate of 1.12 kg AI/ha.

Table 1. Percent disease incidence of treated and untreated corn plants with High Plains Disease on different planting dates in 1995

	% Disease incidence on sampling date ^y						
Treatment (date) ^z	22 May	8 June	23 June	26 July	14 August	31 August	14 September
First planting (21 April)							
Untreated	0.00 a	3.88 a	19.24 a	23.01 a	18.75 a	...	...
One treatment	0.00 a	1.79 a	14.33 a	15.62 b	11.51 b	...	...
Two treatments	0.00 a	1.51 a	12.99 a	15.17 b	11.91 b	...	...
Second planting (18 May)							
Untreated	...	0.00 a	24.08 a	45.77 a	41.89 a	44.50 a	...
One treatment	...	0.00 a	22.46 a	36.13 a	31.62 a	22.09 b	...
Two treatments	...	0.00 a	18.51 a	37.68 a	33.93 a	20.99 b	...
Third Planting (15 June)							
Untreated	...	...	0.00 a	14.16 a	16.55 a	15.89 a	...
One treatment	...	...	0.00 a	11.88 a	12.78 a	11.46 ab	...
Two treatments	...	...	0.00 a	8.20 a	7.74 a	8.15 b	...
Fourth Planting (28 June)							
Untreated	...	...	...	9.77 a	14.75 a	11.10 a	4.92 a
One treatment	...	...	...	13.37 a	17.63 a	13.21 a	5.33 a
Two treatments	...	...	...	11.47 a	17.01 a	15.67 a	7.44 a

^y Means in a column, within planting dates, followed by the same letter are not significantly different ($\alpha = 0.05$; Student-Newman-Keuls test).

^z All treated plots sprayed with Furadan 4F at 1.12 kg AI/ha.

Seasonal percent HPD incidence. At each sampling date in 1994, HPD incidence was significantly higher on corn in the second planting than on corn in the first, third, or fourth plantings (Table 3). There were no significant differences in HPD incidence among corn in the first, third, or fourth plantings except between the third and fourth plantings on 1 August, which was very late in the season.

In 1995, corn in the second planting-date plots had a higher HPD incidence than corn in the first, third, or fourth planting-date plots except for the second sampling

date (8 June), where corn in the first planting-date plots had a significantly higher percentage of incidence than that in the second planting-date plots.

In 1996, corn in the second planting always had significantly higher HPD incidence than corn in the first planting. Between the second and third plantings, corn in the second planting had significantly higher HPD incidence than that in the third planting at all sampling dates except on 16 July, where corn in the second planting had a numerically, but not significantly, higher HPD incidence.

The incidence of HPD varied widely over the 3 years, with the maximum incidence in any planting-date plots occurring in 1995 and the least in 1996 (Table 3). Taking the second planting results as an example, corn in these plots in 1995 had a maximum incidence that was more than 4 times the maximum in 1994 and more than 12 times the maximum incidence in 1996.

HPD incidence in relation to heading dates for winter wheat. Within a given year, the highest HPD incidence occurred in corn grown from the second planting (Table 4). This was true even though the severity of the disease changed dramatically from year to year. When the incidence data from all three years were standardized (by converting the percentage data into a numeric scale), combined across years, and analyzed as a second-order polynomial function of days from wheat heading to corn planting, a strong correlation ($r = 0.94$) was noted (Fig. 1).

DISCUSSION

Use of insecticides-acaricides for HPD control seems impractical. When significant differences occurred in the foliarly applied Furadan experiments, it was late in the season, when mites presumably had ceased migration from wheat. This may be due to a lag in the application of Furadan and an observable reduction in HPD intensity. Many unknown factors, especially mite density, make a clear conclusion impossible. However, corn treated with Counter 15CR granular insecticide in 1996 did show a significant decrease in HPD

Table 3. Percent disease incidence of untreated corn plants with High Plains Disease on different planting dates in 1994 to 1996

Sampling date	Planting ^z			
	1st	2nd	3rd	4th
1994				
13 June	1.33 a	6.00 b	...	...
27 June	1.50 a	7.67 b	...	...
12 July	1.50 a	10.00 b	0.83 a	...
20 July	...	10.33 b	1.67 a	0.00 a
1 August	...	...	1.33 b	0.00 a
1995				
22 May	0.00 a	...	...	...
8 June	3.88 b	0.00 a	...	...
23 June	19.24 b	25.34 b	0.00 a	...
26 July	23.01 b	47.62 c	15.93 ab	9.77 a
1996				
18 June	0.15 a	2.04 b	...	...
2 July	0.07 a	3.13 b	0.02 a	...
16 July	0.05 a	2.75 b	2.34 b	...
29 July	...	2.22 b	0.03 a	...
12 August	...	1.77 b	0.02 a	...

^z Means in a row followed by the same letter are not significantly different (Student-Newman-Keuls test, $\alpha = 0.05$).

Table 4. Maximum percent disease incidence of corn plants with High Plains Disease relative to wheat heading and corn planting dates

Year	Wheat heading date ^z			Corn planting dates				Days heading to planting				Max % disease incidence			
	Irrigated	Dryland	Average	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1994	29 April	8 May	3 May	15 April	16 May	16 June	30 June	-19	13	44	58	1.50	10.33	1.67	0.00
1995	25 April	20 April	22 April	21 April	18 May	15 June	28 June	-2	26	54	67	23.00	47.62	15.93	9.77
1996	3 May	21 April	26 April	18 April	20 May	20 June	...	-9	24	55	...	0.15	3.13	2.34	...

^z Dates are based on records for cv. Tam 107 wheat at Bushland, TX.

Fig. 1. Maximum High Plains Disease (HPD) incidence in corn planted at a given number of days from wheat heading in 1994 to 1996. Maximum HPD incidence is based on a scale of 1 to 4, with 1 having the lowest percentage of disease incidence and 4 having the highest.

incidence over the other treatments and the untreated check. These differences, although statistically significant, would probably not be economically justifiable. All of the granular insecticides used are labeled for control of Western corn rootworm (*Diabrotica virgifera virgifera* LeConte) larvae, and corn that is routinely treated to control this pest may receive some benefit if HPD incidence is reduced.

These results suggest several conclusions about this disease in the Texas High Plains. Based upon an examination of HPD incidence across planting dates and years, and the relation of maximum percent incidence to local wheat heading dates (<2 km), there is a strong seasonal distribution of the disease in corn (Table 1). Older corn may be resistant to the mite or the disease, and corn is most susceptible when planted within a window 10 to 30 days after winter wheat heading (Fig. 1).

Wheat curl mites leave winter wheat as it matures and are wind-blown to other hosts plants such as foxtail (*Setaria* sp.), corn, or volunteer wheat, where they overwinter (6,13,17,19). Although corn is not a preferred host of the wheat curl mite, those that land on corn can survive long enough to transmit pathogens such as HPV (14). It seems, therefore, that corn varieties are exposed to infection with HPV only when wheat curl mites are actively dispersing from one host to another. We used wheat heading dates as a convenient measure of wheat maturity. Few wheat curl mites would leave wheat at the onset of heading, but later, as plants mature and tissue senesces, it becomes an unsuitable host. Peak wheat curl mite dispersal likely occurs 1 to 3 weeks after heading.

The intensity of HPD in corn may be related directly to year-to-year densities of wheat curl mites. We did not sample wheat curl mite densities on wheat or during dispersal; therefore, no direct correlation of mite densities to HPD severity can be made. However, the infection results and the correlation of maximum disease occurrence with wheat heading dates strongly supports wheat curl mite dispersal as one of the primary variables affecting HPD incidence in corn. Wheat does not uniformly come to heading or maturity across a region. Differences in planting dates, moisture levels, varieties, and other factors can influence wheat maturity; therefore, mites may disperse from wheat over a long period of time in the spring. It would be

expected that mite dispersal builds to a maximum and then declines as the wheat matures in an area.

Corn planted 10 to 20 days before wheat heading escapes severe HPD incidence; therefore, it seems that older corn is either such a poor host for wheat curl mites that HPV transmission is negligible, or it becomes resistant to HPV. The HPD incidence recorded on early-planted corn may be due to HPV transmission by early-dispersing mites, or to a percentage of the corn plants in a population being susceptible at any stage. Corn planted 10 to 30 days after wheat heading probably emerges during the height of wheat curl mite dispersal in a given area. This young corn is either a better mite host or is more susceptible to HPV infection. Late-planted corn probably escapes the main mite dispersal and, therefore, even though it may be at a susceptible stage, there are probably fewer mites to transmit the pathogen. The incidence of HPD noted in the later plantings may be attributable to the very last of the mite dispersal from wheat, or due to mites dispersing from an early-maturing overwintering host. Almost 16% of the plants in the third planting in 1995 displayed symptoms of HPD, clearly indicating that some late-season mite activity can occur.

Additional research is needed on the epidemiology of HPD. Wheat curl mite dispersal, temporal density, and distribution need to be studied over a number of years. Research on alternate hosts and corn age in relation to susceptibility to the wheat curl mite and HPV is also needed.

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