Effect of Carbofuran Treatment on Corn Yield, Maize Chlorotic Dwarf and Maize Dwarf Mosaic Virus Diseases, and Leafhopper Populations

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The identification of corn hybrids by brand name and hybrid number is for the benefit of other research workers and does not reflect upon the disease characteristics of other hybrids developed by these companies.

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ABSTRACT

Corn treated at planting time with a systemic insecticide (carbofuran) was evaluated for the incidence of maize chlorotic dwarf (MCD) and maize dwarf mosaic (MDM) diseases, leafhopper populations, and yield under field conditions in Georgia in 1974. Two corn hybrids were used in the experiment; one was susceptible and the other was intermediate in its reaction to both diseases. For the susceptible hybrid in nontreated plots, 73% of the plants were diseased with MCD and 9% with MDM. In carbofuran-treated plots, MCD was reduced approximately two and four times for the susceptible and intermediate hybrids, respectively. The two most abundant leafhoppers in the test field were *Graminella nigrifrons* and *Agallia constricta*. Their population was reduced 65-74% in the carbofuran plots, and there were twice as many leafhoppers associated with the susceptible hybrid as with the intermediate one. Carbofuran did not affect the incidence of MDM in either hybrid, but MDMV infection was significantly greater in the susceptible hybrid than in the intermediate one. In the nontreated plots, the yield of the intermediate hybrid was approximately three times more than the susceptible one. In carbofuran-treated plots, the yield was increased 37% and 125% for the intermediate and susceptible hybrids, respectively.

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A leafhopper-transmitted disease of corn (*Zea mays* L.) causes major economic losses in Georgia (8). Previously, the disease was called corn stunt, but identification tests in 1973 and 1974 demonstrated that the disease was caused by maize chlorotic dwarf virus (MCDV). MCDV is transmitted in a semipersistent manner (10), which suggests that an insecticide might be useful in preventing transmission. A second major disease of corn in Georgia is caused by maize dwarf mosaic virus (MDMV), which is transmitted in a stylet-borne manner by aphids (1). Currently, control recommendations for both diseases include the use of resistant hybrids and eradication of johnsongrass [*Sorghum halepense* (L.) Pers.], an overwintering host for the causal agents (8, 11). Since resistant hybrids are not always available and johnsongrass control is often difficult, the efficacy of a systemic insecticide was tested as a supplementary method of control. We selected carbofuran because it had been used somewhat effectively against a leafhopper-transmitted corn disease in Mississippi (12, 13), and because other systemic insecticides were ineffective (8).

MATERIALS AND METHODS.—*Hybrid selection.*—The test corn hybrids were selected on the basis of differential reaction to MCD and MDM and because of similarity of yield and other agronomic traits under disease-free conditions. Based on 4 years of previous testing, DeKalb 1214 was rated susceptible and Pioneer 3009 was rated intermediate in reaction to both MCD and MDM. When the two hybrids were grown in 10 yield trials from 1970 to 1974, the presence of virus diseases caused a significant yield difference of 33% between the hybrids (Pioneer 3009 = 6592 kg/ha; DeKalb 1214 = 4422 kg/ha), but no differences were detected when the diseases were absent.

Planting and insecticide procedure.— The hybrids were machine planted on May 8, 1974, in the Piedmont Region (Central Branch Station) of Georgia. The soil type was a Davidson clay loam and fertilizer was applied at the rate of 22-20-56 (N-P-K) kg/ha before planting and sidedressed with 84 kg/ha of N when corn plants were 30 cm high. Each plot was 32 rows wide (96.5 cm row width) and 40 m in length. The experimental design was a split plot with hybrids as main plots and insecticide treatments as subplots with five replications.

Carbofuran (2, 3-dihydro-2, 2-dimethyl-7-benzofuranyl methyl-carbamate) was applied in the furrow near the seed row at planting time at a rate of 2.24 kg/ha active ingredient (22.4 kg/ha of Furadan 10 granules).

Disease evaluations.—Six weeks after planting, each plant in rows 5, 12, 19, and 26 of each replication was observed for MCD and MDM. Diseased plants were counted based on symptoms specific for MCD or MDM. Seven weeks later, all plants in rows 2, 8, 14, 19, 25, and 31 were evaluated for percent with MCD, percent dead, and for a disease index which was determined as follows: 1 = healthy, 2 = discolored but no stunting, 3 = stunting up to 25%, 4 = stunting between 25 and 50%, 5 = stunting over 50%.

Insect evaluations.—Leafhoppers were collected 36 days after planting with a sweep net in rows, 5, 6, 11, 12, 17, 18, 23, 24, 29, and 30 of each plot with 25 sweeps per row. Sweeps were initiated 7.6 m in from the border, and

about 16.5 m of row was sampled. Preliminary sampling revealed that two leafhoppers, *Graminella nigrifrons* (Forbes) and *Agallia constricta* Van Duzee, were the most abundant and only these species were counted after each two rows were swept. These and other leafhoppers collected in the sweep nets were placed in containers charged with a toxicant (ethyl acetate) and returned to the laboratory for identification. Also, corn and johnsongrass in the plots were examined 6 weeks after planting for aphids as potential vectors of MDM.

Harvest procedure.—Yield was determined by hand harvesting 6.1 m long subplots near the center of rows 3, 8, 14, 19, 25, and 30 of each plot. The plants were counted, and all ears were harvested and weighed. Thus 700-800 plants were harvested for each treatment. Harvested grain was adjusted to 15.5% moisture.

RESULTS.—*Disease identification.*— Two virus diseases of corn (MCD and MDM) were found in the test field. MCDV was specifically identified by the maize virus research group at the Ohio Agricultural Research and Development Center. Leaves from 20 corn plants with a variety of MCD symptoms (chlorosis, reddening, stunting) were selected in the carbofuran test field and sent to Ohio where they were analyzed for MCDV by rate-zonal serology and micro agar diffusion serology. All twenty samples had MCDV. The identification of MDMV was based on symptomatology, host range, particle characteristics, and serology (8).

Incidence of disease.—The incidence of MCD was relatively high in the test field. The virus infection occurred early with 62% of the plants of the susceptible hybrid DeKalb 1214 (nontreated plot) showing distinctive MCD symptoms within 6 weeks after planting (Table 1). The number of MCD-diseased plants increased to 73% during the following 7 weeks.

In all measurements with MCD, there were significant differences between the susceptible and intermediate hybrids (Table 1). Pioneer 3009 had fewer plants with MCD, a lower disease rating, fewer dead plants, and more healthy plants than DeKalb 1214. In all evaluations except dead plants, the incidence of MCD was reduced significantly in carbofuran plots (Table 1). With carbofuran, the percent of plants with MCD was reduced approximately two and four times for the susceptible and intermediate hybrids, respectively (Table 1). It is significant to note in Table 1 that the susceptible hybrid treated with carbofuran had more disease than the nontreated intermediate hybrid for each evaluation.

The incidence of MDM was relatively low at 6 weeks after planting (Table 1). Later in the growing season, MCD symptoms tended to obscure MDM symptoms and accurate counts of MDM-diseased plants could not be made. The susceptible hybrid DeKalb 1214 had significantly more MDM than the intermediate one, Pioneer 3009 (Table 1). Carbofuran, however, had no effect on the incidence of MDM in either hybrid.

Insect surveys.—The most abundant leafhoppers in the test field were *G. nigrifrons* and *A. constricta*; they accounted for 33% and 32%, respectively, of all leafhoppers collected. Other leafhoppers collected were *Graphocephala versuta* Say, *Sterellus bicolor* (Van Duzee), *Draeculacephala balli* Van Duzee and *Spissistilus festinus* (Say).

A significant reduction in *G. nigrifrons* and *A. constricta* occurred in the plots treated with carbofuran (Table 2). The reduction was 65% and 74% for the intermediate and susceptible hybrids, respectively. It was further noted (Table 2) that the two leafhopper species were about two times as numerous in the nontreated plots of the susceptible hybrid DeKalb 1214 as compared with the intermediate hybrid Pioneer 3009 (Table 2).

The corn leaf aphid, *Rhopalosiphum maidis* (Fitch), both alate and apterous viviparae, was observed on both hybrids and in both carbofuran-treated and untreated plots. Aphid colonies also were observed on johnsongrass in the plots. We did not quantitate aphid levels in the plots, but observed no gross reduction of aphids in the carbofuran plots 6 weeks after planting. Thus, *R. maidis* is the likely vector of the MDMV that occurred in the plots.

The potential movement of leafhopper vectors from nontreated plots to the outside edges of the treated ones was tested two ways. First, a disease rating was made on the first 10 plants at each end of six rows of each plot. The rating was substantially the same as the rating of whole rows (Table 1). Second, the two outermost rows of each plot were compared to two middle rows. Again, there was no indication that the incidence of MCD in the treated plots was influenced by nontreated plots being adjacent to them.

Yield evaluations.—When Pioneer 3009 and DeKalb 1214 were compared in nontreated plots, the yield of the intermediate hybrid was approximately three times as much as the susceptible one (Table 3). Therefore, it was apparent that disease, primarily MCD, had a major effect in the test field. In the carbofuran plots, the yields of the susceptible and intermediate hybrids were increased about 124% and 37%, respectively. Yields were affected

TABLE 1. Incidence of maize dwarf mosaic and maize chlorotic dwarf and disease ratings in corn plots treated with carbofuran

Brand name	Hybrid number	Treatment	Maize dwarf mosaic (%)	Maize chlorotic dwarf		Disease rating (whole plots)	Disease rating (end plants)[b]	Dead plants (%)	Healthy plants (%)
				6 wks (%)	13 wks (%)				
Pioneer	3009	Carbofuran	2 A[a]	3 A	7 A	1.80 A	1.67 A	2 A	62 A
Pioneer	3009	Check	4 A	13 B	29 B	2.15 B	2.20 AB	4 AB	47 B
DeKalb	1214	Carbofuran	7 B	26 C	33 C	2.52 C	2.59 BC	7 BC	36 C
DeKalb	1214	Check	9 B	62 D	73 D	3.13 D	2.89 C	12 C	13 D

[a]Treatment means with uncommon letters in the same column are significantly different, $P = 0.05$, according to Duncan's multiple range test.

[b]Based on the first 10 plants at each end of six rows of each plot.

significantly in the carbofuran plots whether they were based on all plants per plot or on individual plants. Yield reduction was caused by both smaller ears and fewer ears per plant (Table 3).

Carbofuran in virus-free fields.— Since carbofuran is a broad-spectrum pesticide, its effect on corn hybrids in virus-free fields was considered important. During 1972-1974, carbofuran was applied to 20 tests, each with 10-30 hybrids, in the Coastal Plain region of Georgia. The yield was increased in the treated plots by an average of 6.6% or 474 kg/ha. The increased yield was statistically significant in 14 of 20 tests. Thus, yield increases were minor in carbofuran-treated plots in virus-free fields as compared to increases observed in our test field.

DISCUSSION.—These tests support previous studies (5, 6) which indicate that certain systemic insecticides are more likely to prevent the transmission of a circulative virus (MCDV) than a stylet-borne one (MDMV). The incidence of MCD was drastically reduced and MDM was relatively unaffected in carbofuran-treated corn plots.

In the carbofuran-treated plots, three factors appear to be closely related: (i) reduction in the population of leafhoppers, (ii) reduction in the incidence of MCD, and (iii) substantial increase in yield. It is obvious that carbofuran effectively reduced leafhopper populations so that transmission of MCDV was limited to a level which affected the yield. A strong correlation is evident among these factors, indicating that carbofuran can be economically beneficial in areas where MCD is a serious problem.

The greatest relative value of carbofuran may be when it is used in conjunction with corn hybrids rated intermediate in reaction to MCD since the susceptible hybrid treated with carbofuran had more disease than the nontreated intermediate hybrid (Table 1). Furthermore, although the relative yield increase in carbofuran plots was greater with the susceptible hybrid (124%) than the intermediate one (37%), the actual yield increase was similar for both hybrids. Based on 7 years of evaluating virus diseases in corn hybrid yield trials (8, 9), it appears that carbofuran improved the disease situation with the intermediate hybrid to make it similar to hybrids rated resistant. Resistant hybrids are satisfactory in controlling MCD, but they have two disadvantages: (i) in 7 years of testing, only three hybrids have consistently performed well under severe disease conditions in Georgia, and (ii) the agronomic traits of the hybrids are not uniformly desirable for all corn producers.

Three factors were probably important in causing the high incidence of MCD in the test field: (i) the disease had been present in the field for at least 5 years, (ii) johnsongrass was abundant and provided a readily available, internal source of inoculum, and (iii) there was an early activity of leafhoppers based on their abundance at 5 weeks after planting and because of the large percentage (62) of MCD-diseased plants at 6 weeks.

Although systemic insecticides have been used previously in corn tests, it is difficult to compare with our results because of confusion concerning the identity of the causal agent(s) of leafhopper-transmitted corn diseases. Prior to 1972, the major leafhopper-transmitted disease in the southern United States was called corn stunt and was believed to be caused by a mycoplasma or spiroplasma (7). MCDV was identified in 1972 (4, 11), and it appears to be the major leafhopper-transmitted corn disease in Georgia, based on symptomatology and serological tests with corn leaf samples from various parts of the state.

Graminella nigrifrons is an efficient vector of MCDV (10), and it was the leafhopper probably responsible for the transmission of MCDV in the test field. *Agallia constricta* was equally abundant, and it has been implicated as a vector of certain plant viruses (3). It is not known if *A. constricta* transmits MCDV, but this potentiality should be studied in view of the high numbers collected. Carbofuran is known to be highly toxic to leafhoppers (2), but Pitre (13) found no significant reduction in *G. nigrifrons* in carbofuran-treated corn plots at 35 days after treatment. In contrast to this observation, our results showed that the populations of *G. nigrifrons* and *A. constricta* were reduced about 70% at five weeks after application of carbofuran.

Resistance to MCD in Pioneer 3009 appeared to be due

TABLE 2. Number of *Graminella nigrifrons* and *Agallia constricta* in corn plots treated with carbofuran[a]

Brand name	Hybrid number	Mean no. of leafhoppers/ 50 sweeps	
		Carbofuran	Check
Pioneer	3009	0.60[b]	1.68
DeKalb	1214	0.84	3.16

[a]Number of *G. nigrifrons* and *A. constricta* were 51% and 49% of totals, respectively.

[b]A "t" test showed that the difference between carbofuran and check was significant $P = 0.01$ level of probability and the difference between hybrids was significant $P = 0.05$.

TABLE 3. Yield of two corn hybrids grown in a field with a high incidence of maize chlorotic dwarf and in which plots were treated with carbofuran

Brand name	Hybrid number	Treatment	Yield		Ears/plant	Wt/ear (g)
			kg/ha	Ear wt/plant (g)		
Pioneer	3009	Carbofuran	6648 A[a]	200.0 A	0.89 A	224.2 A
Pioneer	3009	Check	4842 B	148.0 B	0.82 AC	179.4 B
DeKalb	1214	Carbofuran	3493 C	129.8 C	1.10 B	116.2 C
DeKalb	1214	Check	1561 D	57.4 D	0.76 C	72.2 D

[a]Treatment means with uncommon letters in the same column are significantly different, $P = 0.05$, according to Duncan's multiple range test.

to at least two factors: (i) resistance to the leafhopper vector, and (ii) reduced effect of the pathogen. Nontreated plots of the susceptible hybrid DeKalb 1214 had nearly twice as many leafhoppers and 2.5 times as many MCD-diseased plants as Pioneer 3009. This may indicate leafhopper preference for DeKalb 1214 or nonpreference for Pioneer 3009. A second factor was a difference in disease severity between the two hybrids. The susceptible one had 6.3 times as many plants with the highest disease rating (over 50% reduction in plant size). Thus, these results may have important implications in selection of corn inbreds in breeding programs and to the epidemiology of MCD.

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