Disease Losses in Carnations Infected with *Gibberella zeae*

R. W. Stack, R. K. Horst, P. E. Nelson, and R. W. Langhans

R. W. Stack and R. K. Horst, former graduate student and associate professor, respectively, Department of Plant Pathology, Cornell University, Ithaca, NY 14853; P. E. Nelson, professor, Department of Plant Pathology, Pennsylvania State University, University Park, PA 16802; and R. W. Langhans, professor, Department of Floriculture and Ornamental Horticulture, Cornell University, Ithaca, NY 14853. Present address of senior author: Department of Plant Pathology, North Dakota State University, Fargo, ND 58102.

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ABSTRACT

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Three crops of carnations were grown under conditions similar to those in commercial greenhouses. Young plants were inoculated with conidial suspensions of *Gibberella zeae* when pinched, and typical symptoms of Fusarium stem rot developed. Flowers were cut as in a commercial crop. Infection by *G. zeae* significantly reduced the number of flowers and their quality, based on a standard grading system for carnations. Inoculated plants required as much as 2 wk longer than noninoculated plants to produce a flower crop.

Additional key words: Fusarium graminearum

Fusarium stem rot incited by *Gibberella zeae* (Schw.) Petch (Imperfect stage *Fusarium graminearum* Schwabe) is a potentially serious disease of florists' carnation (*Dianthus caryophyllus* L.) (7). Stub dieback is one phase of Fusarium stem rot of carnation, which has been reported to be caused by several species of Fusarium, including *F. graminearum, F. culmorum,* and *F. avenaceum* (1,7).

Some workers (2,11,12) have stated that Fusarium stub dieback, although common, has no economic importance; others (3,4) consider the disease to be potentially serious, especially on older plants. A recent severe outbreak of the disease was documented (7).

No figures have been reported on losses to stub dieback alone. The incidence of Fusarium stem rot was reported as 10% of all plants in Denmark (4), however, and we estimate the incidence of the disease in the eastern United States to be at least 10%. Our experiments were designed to gain some estimates of the nature of losses due to Fusarium stem rot and were confined to Fusarium stub dieback and stem rot caused by *G. zeae.*

MATERIALS AND METHODS

Growing conditions. Rooted carnation cuttings, provided by a commercial propagator, were planted in raised benches 0.92 m wide, 1.25 m deep, and varied lengths. The beds were filled with a soil mixture containing two parts topsoil, two parts peat, and one part coarse perlite. Fertilizer was added on the basis of soil tests for major elements (N, P, K, Ca, soluble salts, and pH). The soil was steamed in the bench at 85 C for 30 min before planting. Plants were watered weekly with a solution containing N and K each at 200 mg/L.

A minimum 11 C night temperature and 16 C day temperature were maintained from October to April; temperatures were higher in other months. Temperature and relative humidity under the plant canopy were monitored with a hygrothermograph and checked periodically with a wet-bulb psychrometer.

Inoculum preparation and application. The original isolate of *G. zeae* (*F. graminearum*) used in these studies was R-762 from the Fusarium Research Center, Pennsylvania State University, University Park, PA 16802. This pathogen produced both sporodochia and perithecia on carnation plants under greenhouse conditions in some of these experiments. Specimens of carnation stems bearing fruiting structures of *G. zeae* are deposited in the Plant Pathology Herbarium at Cornell University, Ithaca, NY 14853 (CUP 53528). Inoculum preparation and inoculation procedures followed those previously reported (9).

Disease ratings. Because stems could not be split open to determine lesion presence and size until the end of the cropping period, early estimates of the disease level were based on the development of external symptoms of stub dieback (eg, shrivelling of the stub, necrosis of leaves, brown lesions extending down the stem, and stunting or wilting of side shoots). Plants showing these symptoms are referred to as symptomatic. Plants lacking such symptoms, even if internal lesions were found later, are referred to as asymptomatic.

Grading of flowers. Quality of cut flowers was categorized by one of four grades determined by diameter and form of flower and length and strength of stem. Flowers had to meet all requirements to be placed in a grade. The four grades were: Extra Fancy (7.5-cm minimum flower diameter, 76-cm minimum stem length); Fancy (7-cm minimum flower diameter, 53-cm minimum stem length); No. 1 (5.5-cm minimum flower diameter, 37-cm minimum stem length); Design (no minimum flower diameter, 22-cm minimum stem length). Mechanical damage during harvesting or grading did not downgrade the flowers. Stems had to be stiff enough to hold the flower upright (less than 30° bend from vertical). Flowers with split calyces were graded Design.

Winter 1974 crop. In July 1974, 720 rooted cuttings of Improved White Sim were planted in a greenhouse bench. Plants were spaced 15 cm apart each way in 14 blocks, leaving several border rows at each end. Three weeks after planting, all single terminals were pinched, leaving four or five nodes; the stubs in 12 blocks were inoculated with *G. zeae* by placing a droplet on the cut surface. During the cropping period plants were removed periodically from six blocks. Cropping results are therefore based only on the six intact inoculated blocks (288 plants) and the two uninoculated blocks. During the incubation period average temperatures were

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12–16 C at night and 20–27 C during the day.

All plants were examined for symptoms before flowering and again at the end of the experiment by noting the number of stubs left from cutting flowers, the number and size of killed shoots, and the presence and size of internal lesions from stub inoculations.

Flowering commenced 18 wk after inoculation, and flowers were cut twice a week. A separate record was kept on the flower production from each plant. The flowers from each block were grouped before grading.

Summer 1975 crop. In March 1975, 162 rooted cuttings of each of five carnation cultivars were planted. The plants were spaced 15 cm apart in rows across the bench and 12 cm between rows (135 rows of six plants each). Six blocks of 20 rows were marked off and half the total number of plants were inoculated in each block, leaving border rows at each end of the bench. Every block contained four rows each of Improved White Sim, Red Alaska, Orchid Beauty, Flamingo Sim, and Yellow Dusty. The location of the cultivars was random in each block.

Individual plants were carefully examined for symptoms before flowering, which commenced 9 wk after inoculation. Flowers were cut as they opened and records kept for each plant. Flowering continued for 11 wk, after which all plants were removed from the bench and examined individually. Stems were split lengthwise and the presence and size of lesions determined. Flowers were not graded in this experiment.

When the plants were removed for examination after the experiment, the number of dead shoots on symptomatic plants was recorded, as was the number of primary shoots that had not bloomed.

Winter 1975 crop. In July 1975, 240 rooted cuttings each of California Red, Improved White Sim, and Pink Ice were planted in a greenhouse bench prepared as previously described. Two blocks with border rows were left at each end. In the blocks each cultivar was planted at three densities: 32, 62, and 96 plants per square meter. Three weeks after planting all plants were pinched. In one block all plants were inoculated; in the other, half the total number of plants were inoculated.

The incidence of symptomatic plants was noted 15 wk after planting. Thirty-two weeks after planting, all plants were removed from the bench, cut open, and examined for presence and size of lesions, occurrence of dead shoots, and sporulation of the pathogen. Flowering commenced 15 wk after planting and flowers were cut twice weekly for 17 wk. The source plant for each flower was recorded and the flowers were graded.

TABLE 1. Size and quality of carnations cut from plants inoculated with *Gibberella zeae* in the winter 1974 crop

Plant character[a]	Uninoculated (no.)	Inoculated[b] (no.)
Total plants	96	288
Proportion of plants with symptoms [c]		
Early	0	24% **
Late	0	34% **
Number of flowers cut		
Total	399	898
Per plant	4.16	3.12*
Proportion of flowers graded fancy and better		
First 70% cut	82	67 **
Total cut	74	64 *

[a] The first 70% of the crop was cut off by the sixth week after flowering began. Total cropping period was 14 wk. $P = 0.01$ (**); $P = 0.05$ (*) (χ^2 test).

[b] Plants received a droplet of *G. zeae* spore suspension at time of pinch, 4 wk after planting rooted cuttings.

[c] Early symptoms (stub shrivelling, necrosis of leaves, and brown stem lesions) were visible before flowering began. Late symptoms were visible at the conclusion of the experiment, 32 wk after inoculation, and include plants with early symptoms.

RESULTS

Flower crop production. *Winter 1974 crop*. The average incidence of symptomatic plants at the beginning of flowering in the inoculated plants was 24% (range within blocks was 17–33%). Uninoculated plants produced an average of 4.16 flowers, and inoculated asymptomatic plants produced 3.81 flowers (significantly less than the uninoculated plants, $P = 0.05$). Inoculated symptomatic plants had an average of 1.69 flowers (Table 1). Flower production for separate blocks showed a significant negative correlation with the incidence of symptomatic plants at the start of the flowering period ($r = -0.94$, $P = 0.05$).

Summer 1975 crop. The mean yield of flowers was 5.17 for uninoculated plants, 2.37 for inoculated and symptomatic plants, and 4.85 for inoculated, asymptomatic plants (Fig. 1). There were significantly fewer flowers in inoculated asymptomatic plants and in symptomatic plants. Two cultivars (Improved White Sim and Yellow Dusty) displayed too few asymptomatic inoculated plants for proper comparisons. The number of shoots per plant was the same for symptomatic as for asymptomatic plants. In this case the number of shoots per plant is close to the potential number, assuming one per node from the original cutting.

Winter 1975 crop. The uninoculated plants yielded an average of 3.01 flowers and the average for inoculated plants was significantly ($P = 0.01$) lower, 2.24 flowers. Inoculated plants were classified in four categories by the presence and size of internal lesions and external symptoms. As disease severity increased, yield of flowers decreased (Table 2).

The reduction in yield associated with various levels of disease was approximately the same for all cultivars (Fig. 2). There were significant differences in effect of disease on yield at the different planting densities (Fig. 3). At the highest plant denisty (96/m^2)

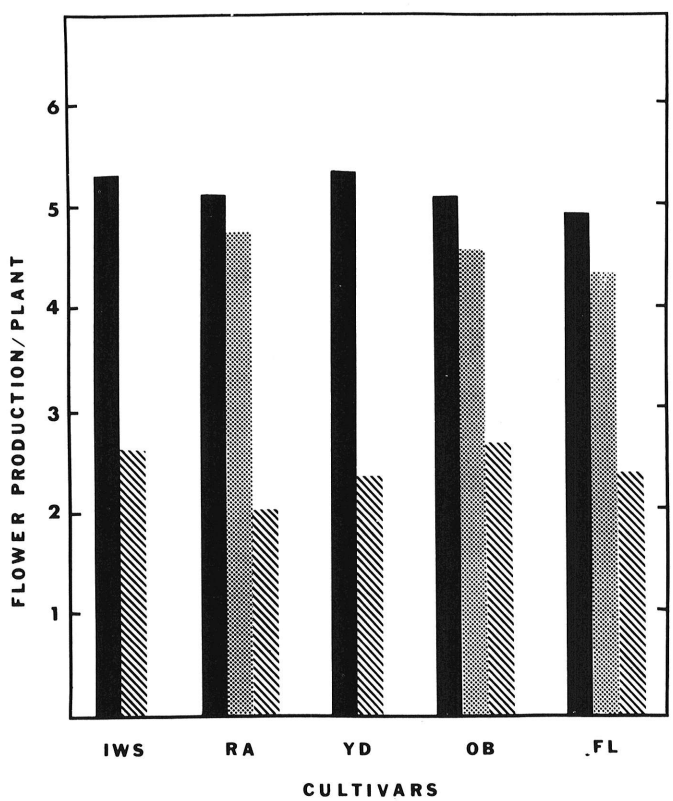

Fig. 1. Effect of inoculation with *Gibberella zeae* on flower production by five carnation cultivars. Each cultivar contained 72 inoculated and 72 uninoculated plants in six replicates. Solid bars = uninoculated plants; dotted bars = inoculated, asymptomatic plants; hatched bars = inoculated, symptomatic plants. Cultivars: IWS = Improved White Sim; RA = Red Alaska; YD = Yellow Dusty; OB = Orchid Beauty; FL = Flamingo. Differences between treatments shown are significant for all cultivars at $P = 0.05$ (χ^2 test).

there was no effect of inoculation unless external symptoms were seen (disease ratings 3 and 4), but at the lowest plant density ($32/m^2$) there was a significant yield reduction associated with disease ratings 2 and above. In the intermediate plant density ($62/m^2$) all inoculated plants showed yield reductions.

Crop quality. *Winter 1974 crop.* Six weeks after the 1974 crop began to flower, 70% of the crop had been cut. There was a significant ($P = 0.05$) negative correlation ($r = 0.46$) between the quality of flowers (the percent in the highest two grades, ie, Fancy and Extra Fancy) and the incidence of symptomatic plants for the separate blocks. The overall quality of flowers from the uninoculated blocks (74% of the total graded Fancy or better) was significantly higher ($P = 0.01$) than the quality for the inoculated blocks (64% of the total graded Fancy or better) (Table 1).

Winter 1975 crop. Based on 1,889 flowers cut in 1975, the proportion of flowers in the higher grades among those from inoculated plants (49% Fancy and Extra Fancy) was significantly smaller than that from uninoculated plants (56% Fancy and Extra Fancy). Because the total number of flowers from inoculated plants also was lower, the combined effect was 395 and 607 high grade flowers from inoculated plants and uninoculated plants, respectively.

Crop timing. *Winter 1974 crop.* The production of flowers by symptomatic plants was delayed by more than 2 wk, based on the time needed from the beginning of flowering until 70% of the flowers are cut (Fig. 4). Evaluated as actual numbers of flowers cut, symptomatic plants produced less than half as many flowers as asymptomatic ones (Table 1).

Summer 1975 crop. The cropping history was reconstructed from records for each flower cut. The delay of inoculated plants (87% symptomatic) to reach 70% crop cut, compared with the time of uninoculated plants to reach the same point, was 0.8 wk (range 0.7–1.0 for different cultivars), which was a significant difference in flowering time ($P = 0.05$).

Winter 1975 crop. The delay in flowering by inoculated plants was not as pronounced during early flowering as in previous experiments. A longer delay occurred about 5 wk into the flowering period, at which time about half the flowers had been cut. To reach the 70% cut point, the inoculated plants took 1.5 wk longer than uninoculated ones. The 100% cut on which calculations are based represents all of the open flowers cut during the 13-wk cropping period; however, at the end of the experiment many more buds were not opened on the inoculated plants than the uninoculated, suggesting that the delay associated with inoculation may have been greater if the cropping period had been longer.

Return crop potential. *Winter 1974 crop.* When this experiment ended, about 93% of all potential first crop flowers had opened and

TABLE 2. Size and quality of carnations cut from plants inoculated with *Gibberella zeae* in the winter 1975 crop

Plant character	Uninoculated	Number of inoculated plants with disease rating:[x] 1	2	3	4
Total plants	360	90	58	198	14
Number of flowers cut per plant[y]	3.01 a	2.84 ab	2.44 bc	2.02 c	0.71 d

[x] The 360 inoculated plants received a droplet of *G. zeae* spore suspension on cut stub. Disease ratings: 1 = externally asymptomatic, lesion confined to stub; 2 = externally asymptomatic, lesion extending past at least one node (avg. = 2.2 nodes); 3 = externally symptomatic with necrosis of one to three branches, lesion not reaching base of plant; 4 = plant dead or living with more than three killed shoots and lesion extending to base of plant.
[y] Means followed by same letter are not significantly different at $P = 0.05$ according to a Duncan's multiple range analysis.

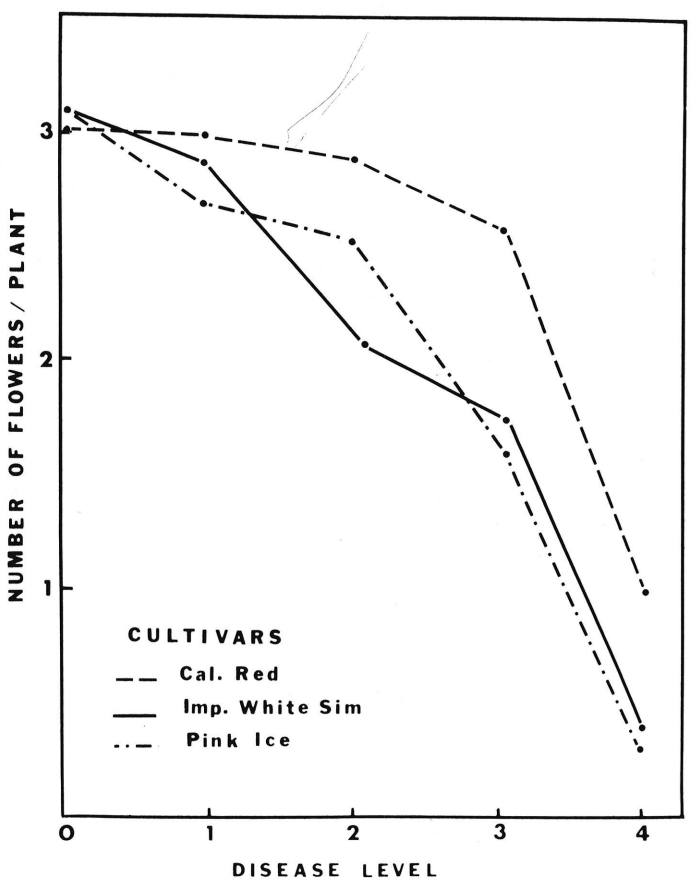

Fig. 2. Effect of inoculation with *Gibberella zeae* on carnation flower production. Disease severity: 0 = uninoculated; 1 = inoculated, asymptomatic; 2 = moderate stem lesion but no shoot mortality; 3 = moderate stem lesion and one to three shoots killed; 4 = extensive stem lesion and more than three shoots killed.

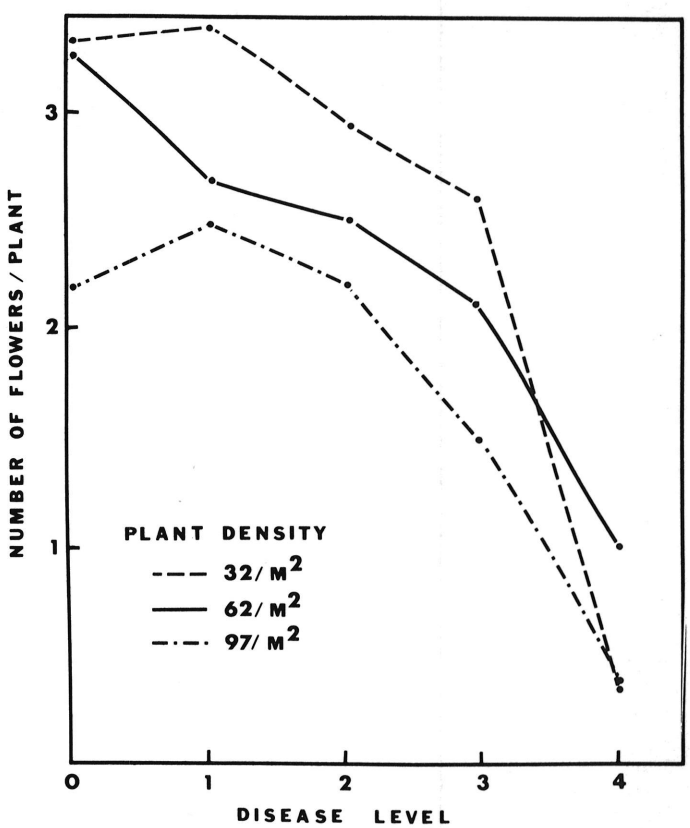

Fig. 3. Interaction of disease after inoculation with *Gibberella zeae* and of planting density on carnation flower production. Disease severity: 0 = uninoculated; 1 = inoculated, asymptomatic; 2 = moderate stem lesion but no shoot mortality; 3 = moderate stem lesion and one to three shoots killed; 4 = extensive stem lesion and more than three shoots killed.

been cut. The remaining primary shoots (first crop, those arising directly from the main stem) were counted, and the number was added to the number of flowers already cut to obtain the number of first crop stems that the plant produced; in symptomatic plants, the number of dead shoots also was noted (Table 3). The number of secondary shoots (those arising from primary stems and giving rise to the return crop if plants remained in production) that were sufficiently developed to flower by June (3 mo later) also were counted (Table 3). Symptomatic and asymptomatic plants had about one secondary shoot for each live primary shoot.

DISCUSSION

Crop losses. Losses associated with Fusarium stub dieback are of three types: reduction in the number of flowers cut, delay in cropping, and reduction in grade of flowers. Although the incidence of infection was higher in these experiments than might be expected in a commercial greenhouse, the nature of the losses would be the same. In severe epidemics in commercial greenhouses, the incidence of infection may be greater than 50%.

The presence of *G. zeae* in plants without external symptoms causes a slight but significant reduction in yield compared with that of uninoculated controls. We anticipated that the direct loss from shoot mortality might be partly mitigated by compensation, ie, affected plants might form extra shoots to replace those killed. This did not happen in the first crop or the return crop. Thus, yield reduction in the first crop carries into successive crops. Whether compensation in number of shoots would occur during the summer between first and second year in a 2-yr crop cannot be determined from these experiments, but Holley (5) found that removing 42% of the plants in a bench during the summer reduced yield by only 19% during the second year of cropping. This suggests that some compensation occurred.

Plants grown through a second season usually are pruned to prevent over-production of flowers, which tends to reduce grade and summer production in favor of winter flowering (6). Infections that caused mortality during the first season and some that did not probably would kill shoots during the second season.

The delayed flower production due to stub dieback shown in these experiments was hitherto unknown. Cropping time may be delayed for both environmental and cultural reasons. Some delays are amenable to modification but others are beyond the grower's control (6). This delay is of less concern to growers who raise carnations for continuous production than to growers who crop for a particular date, but even in continuous production, the accumulated delays could amount to 4–6 wk. All of the loss would appear as buds still unopened at the time plants are discarded.

The crop distribution caused by some pinching methods is similar to that caused by stub dieback. In particular, the effect of the procedure termed "pinch-and-a-half" (rooted cuttings are cut back several weeks after planting, as in a single pinch, and half of the shoots are cut back again at a later time, which varies with the season) is to delay the crop but spread it out (6). This is the same effect seen in plants with stub dieback (Fig. 4), with the important difference that pinch-and-a-half plants do not have a reduced total yield as do plants with stub dieback. Much of the observed delay in flowering time occasioned by stub dieback probably is due to this pruning effect of shoot necrosis.

The recurrent shifts between bright sunny and cloudy weather (which occur in Ithaca during winter) and poor temperature control in the greenhouse (which allow wide fluctuation in temperature during the flowering time) both contributed to variability in grading. Both factors also lead to an increase in split calyces, which cause flowers to be placed in the lowest grade category. Usually the best flowers split first (8), thus lowering the overall grade for the crop.

Using the loss rates obtained in these experiments and assuming a 10% infection rate in all stubs, we calculated that loss from stub dieback for a 2-yr carnation crop would be 1–2% of all flowers. The 1969 value of the carnation production east of the Mississippi was about $9 million (10), and the loss might be $100,000 to $200,000 per year. The cost of control probably would be greater than this 2% of crop value. However, carefully timed control procedures applied under selected conditions might be economically worthwhile.

Based on our success in reproducing Fusarium stem rot epidemic symptoms by inoculating stubs at pinching, we suggest that the Fusarium stem rot outbreaks in mature plants begin as stub infections early in the crop's history.

TABLE 3. Potential return crop in carnations inoculated with *Gibberella zeae* in the winter 1974 crop

	Number of inoculated plants[a]	
	Asymptomatic	Symptomatic
Total plants[b]	189	81
First crop stems (per plant)		
Live	4.28	2.17
Dead	0	2.59
Return crop stems [c]	4.80	2.16
Ratio of return crop stems to live first crop stems	1.12	1.00

[a] Plants received a droplet of *G. zeae* spore suspension on cut stubs.
[b] Only plants alive at the end of the experiment (32 wk after inoculation) were counted; 18 of the original 288 plants died.
[c] First crop stem are those arising directly from the original pinched cutting. Return crop stems are those that arise as side shoots on the first crop stems.

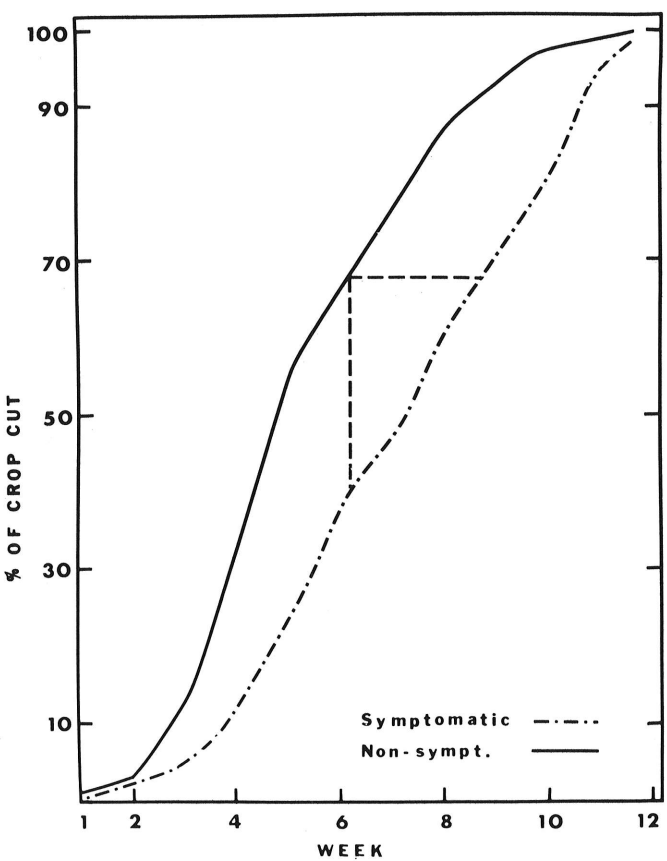

Fig. 4. Influence of *Gibberella zeae* on carnation flower production in winter 1974 crops. Symptomatic plants develop flowers more slowly than asymptomatic plants. Solid line = cumulative percent of crop cut from asymptomatic plants. Dotted line = cumulative percent of crop cut from symptomatic plants. Horizontal dashed bar indicates 2.3-wk delay in reaching 70% of crop cut. Vertical dashed bar indicates percent reduction in crop cut from symptomatic plants when flowers from asymptomatic plants were 70% cut. Curves based on 100% cut 14 wk after beginning of flowering (horizontal axis).

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