Epidemiology of Tomato Spotted Wilt in Pepper and Tomato in Southern Georgia

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ABSTRACT

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The spatial distributions of symptomatic tomato and pepper plants infected with tomato spotted wilt virus (TSWV) were mapped over time in field studies in 1990 to 1992. Disease gradients occurred in some tomato transplant beds and pepper fields but were not observed in tomatoes grown to maturity. In 1990 and 1991, an increasing gradient emanated from the eastern edge of tomato transplant beds and led to adjacent tobacco plots containing TSWV-infected plants. In addition, gradients within each block emanating from the edge adjacent to fallow alleys were observed within the primary disease gradient in 1990. A gradient also occurred both down the row and across cultivars in a commercial pepper field in 1990. The gradient failed to flatten over time, a possible indication of lack of secondary disease spread. Tests for aggregation supported the contention that there was limited secondary spread within pepper fields and tomato plots and that most infections arose from primary transmission. Clipped plants from tomato transplant beds had no higher incidence of TSWV in grow-out tests than did nonclipped plants. Reduced yields were significantly correlated with time of first symptom expression in tomato, with plants that were symptomatic earlier in the season yielding less fruit per plant by weight.

Tomato spotted wilt (TSW), caused by a thrips-vectored tospovirus (TSWV), is a serious problem in peanut, pepper, tobacco, and tomato in the southeastern United States (3,4,8). Incidence of TSW in Georgia has increased on pepper and tomato since it was first observed on tomato transplants in 1989 (6). Currently, TSWV can account for up to 100% loss in individual pepper and tomato fields. In addition to the local problem, infected transplants grown in southern Georgia have been implicated in TSW outbreaks in Georgia as well as in the northern United States and Canada (12,13). Since TSWV does not appear to be endemic in northern areas (excluding survival in greenhouses), the amount of secondary spread, if any, is of paramount importance and concern, not only to those receiving the plants, but also to transplant growers. The potential of extensive spread of TSWV among transplants by late-season clipping (6), resulting in delayed symptom expression until after inspection and sale, was unknown. Another concern is the potential of a few diseased transplants to serve as sources of virus for secondary spread once set within production fields. Finally, detailed knowledge, especially in the southeastern United States, of the impact of TSWV infections on yield was limited.

TSWV is vectored by thrips, including the tobacco thrips, *Frankliniella fusca* (Hinds), and the western flower thrips, *F. occidentalis* (Pergande) (5,11). It has been established that thrips larvae acquire the virus but usually do not transmit it (1,11). The incubation period in thrips larvae, depending on species, ranges from 4 to 18 days. In order for the larvae to become infective, the incubation period must be completed before pupation (14). However, if the larvae do become infective, they maintain the virus into adulthood. Transmission to a susceptible plant host occurs through feeding activities of adults. Although adult thrips are capable of transmitting the virus for long periods of time and are capable of transmitting to a multiple number of plants, they have a midgut barrier that prevents virus acquisition and subsequent transmission (16). As a consequence, thrips have to complete a life cycle for secondary spread to occur. They acquire the virus in the larval stage on an infected plant and then complete metamorphosis into an adult, migrate to a healthy plant, and transmit the virus. The time required to complete this process would limit the amount of secondary transmission within a normal growing season.

The objective of this study was to analyze the spatial and temporal distributions of TSW-infected pepper and tomato plants (both transplants and production plantings) to ascertain the importance of secondary spread to TSW epidemics. We also correlated tomato yields with date of first foliar symptom expression to evaluate the effect TSWV has on yield reduction.

MATERIALS AND METHODS

Experimental sites, plot preparation, and maintenance. Transplant beds were established on Fuquay loamy sand soil in one site (western) in 1990 and two locations (western and central) in 1991 at the Blackshank Farm of the Coastal Plain Experiment Station near Tifton, Georgia. Rye (*Secale cereale* L.) was established as a winter cover crop between plantings, and strips of rye were maintained as windbreaks around the perimeter of the plot area. The cover crop was turned while still green with a moldboard plow, and the soil was truncated with a harrow and rototiller into a texture suitable for precision seeding. Napropamide (Devrinol) at 3.4 kg/ha, fenamiphos (Nemacur) at 8.99 kg/ha, and metalaxyl (Ridomil) at 2.34 liters/ha were incorporated into the soil for control of weeds, nematodes, and damping-off, respectively. Fertilizer (6-12-6) at 343 kg/ha was broadcast and incorporated into the soil. A side-dressing (448 kg/ha of 6-12-6) was applied 4 weeks after planting. Using a Stanhay belt-system precision seeder (Stanhay Webb Ltd., Suffolk, UK CB8 7HD), coated tomato seeds (cultivar H-722 in 1990 and Ohio-7870 in 1991) were direct-seeded on 14 March 1990 and 27 March 1991. Tomatoes were planted in raised beds 1 cm apart in four rows spaced 35 cm apart. Each plot was 15.24 m long and 18.29 m wide and was replicated four times. Each replicate was separated by a fallow alley 3.05 m long. All plots were sprayed on a 7- to 10-day schedule with carbaryl (Sevin 80%) at 2.2 kg/ha and chlorothalonil (Bravo 720) at 2.63 kg/ha for insect and fungal leaf spot control, respectively. Irrigation was applied as needed by solid-set overhead sprinklers. Treatments consisted of clipping (to promote uniform growth and to maintain a final plant height of 25 cm) on a 3- to 4-day schedule during the final 2 weeks or not clipping. Transplants were harvested by hand, and 100 from each treatment (clipped and nonclipped) were transplanted in 30.5-cm-diameter pots of commercial

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potting mix and maintained in the greenhouse.

Tomato plots, simulating processing tomato production, were established on a 0.2-ha site under center pivot at the ABAC Farm near Tifton in 1990, 1991, and 1992 on a Tifton loamy sand soil. Transplant beds were prepared by deep-turning with a moldboard plow and leveled into a 1.9-m-wide bed with a bed shaper. Tomato plants were transplanted in rows 91 cm apart with a two-row transplanter. Spacing within the row was 61 cm. Tomato cultivars for 1990, 1991, and 1992 were Heinz 8245, Heinz 7983, and Floridade, respectively. Transplanting dates were 19 April 1990, 29 April 1991, and 28 March 1992. Metribuzin at 0.56 kg/ha was applied within 3 days after transplanting. All crop production materials (herbicides, fungicides, insecticides, and fertilizer) were applied through the center pivot irrigation system based on soil test or scouting as recommended by the University of Georgia Cooperative Extension Service. Amounts and time of application varied from year to year.

Commercial pepper fields in Cook County (near Adel, GA) in 1990 and in Coffee County (near Douglas, GA) in 1991 were used to monitor the incidence and spatial distribution of TSW. Fields were selected based on growers' reports to county agents of problems observed immediately after transplanting. The pepper cultivars Marengo, Jupiter, and Keystone Resistant Giant were in adjacent plantings at the Cook site in 1990. The cultivars Jalapeno, Yolo-L, and Jupiter were within the same field in Coffee County in 1991. All crop production practices and inputs were as recommended by the University of Georgia Cooperative Extension Service.

Data collection and analysis. Beginning on 2 April 1990 and 9 April 1991, tomato transplant beds at the Blackshank farm were examined five times at a 7-day interval. Beginning on 18 May 1990, 15 May 1991, and 12 May 1992, production tomato plots at the ABAC center pivot site were examined five to seven times on a 7- to 14-day interval. Pepper fields were monitored on a 7- to 14-day interval beginning on 6 April 1990 and 29 April 1991. Colored surveyors' flags (a different color for each examination date) were placed adjacent to symptomatic plants. Tissue samples were taken sporadically from symptomatic plants and tested with a commercial enzyme-linked immunosorbent assay (ELISA) (Agdia, Elkhart, IN) as described by Culbreath et al. (2). In transplant beds, flag positions for each rating period were recorded by row and distance (nearest 0.025 m) from the eastern edge of the plot area. In production plots, stand counts were taken prior to the initial rating, and flag positions for each rating period were recorded by row number and plant number within a row.

Distribution of diseased plants was analyzed by linear regression, corrected doublet analysis, and ordinary runs to test for aggregation (10,15,17). Z-statistics were calculated by rows and compared by chi-square analysis (15). Disease severity values were transformed to log values, and basic infection rates were calculated (18). Tomato plants were separated into groups based on time of initial symptom expression; then fruit were harvested, weighed, and recorded as kilograms per individual plant, and results were analyzed by linear regression (15).

RESULTS AND DISCUSSION

Disease incidence and spatial patterns of disease varied among location, plant type, and year. In 1990 and 1991, a gradient emanated from the eastern edge of tomato transplant beds at the western site (Fig. 1A). The highest incidence of disease in the tomato beds was adjacent to tobacco plots containing TSWV-infected plants. Disease patterns in each block in 1990 indicated that gradients existed within the primary gradient. Disease incidence within blocks was greater along the eastern edge of each plot adjacent to a fallow alley (Fig. 2). It is not known if these patterns within a gradient were caused by thrips actively attracted to the edge of each block adjacent to a fallow area, air currents passively depositing thrips at the edge of each block, or some other unknown reason.

Based on 0.025 m as the distance between adjacent plants in a transplant bed, both ordinary runs and corrected doublet analysis indicated no aggregation (P = 0.05) of TSWV-infected plants by harvest

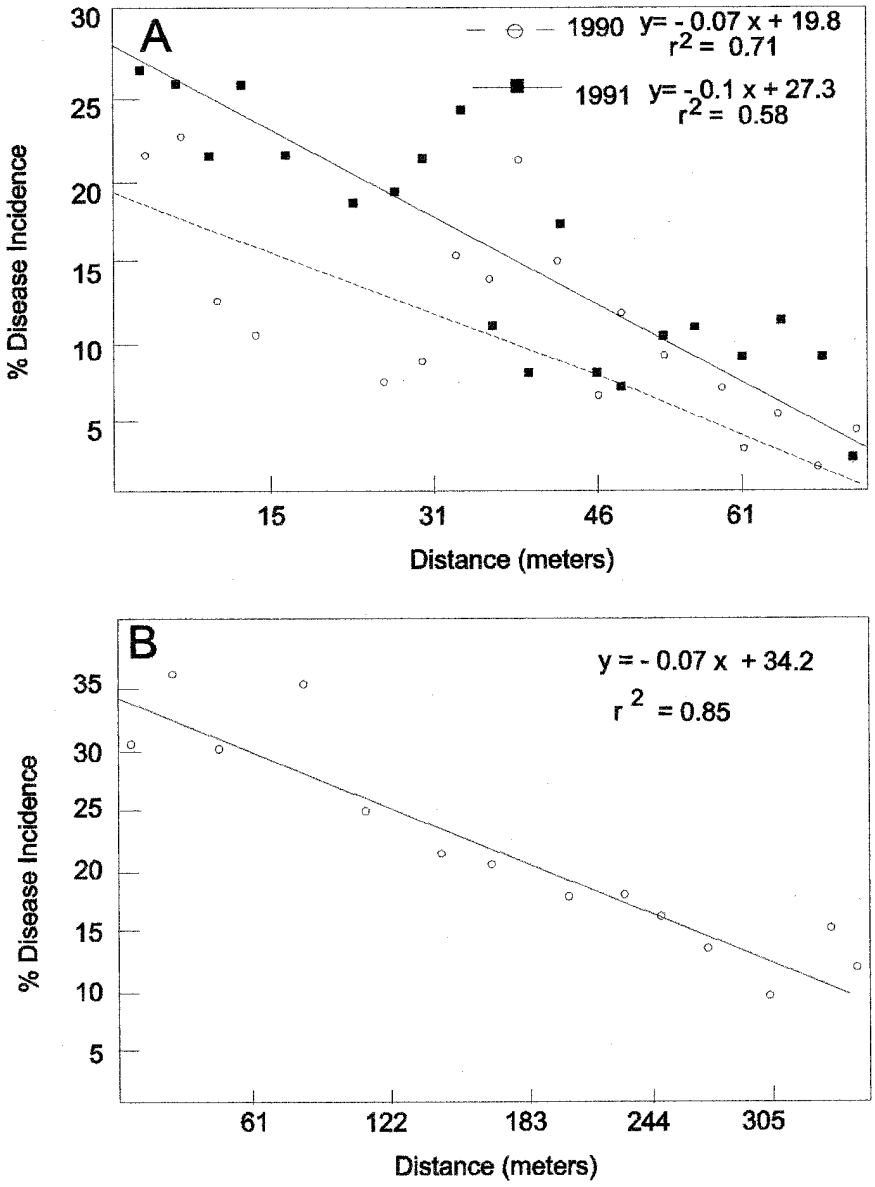

Fig. 1. Primary disease gradients indicated by linear regression of final disease incidence versus distance in meters in **(A)** tomato transplant plots in southern Georgia in 1990 and 1991, and **(B)** a commercial pepper field at Cook site A in southern Georgia in 1990.

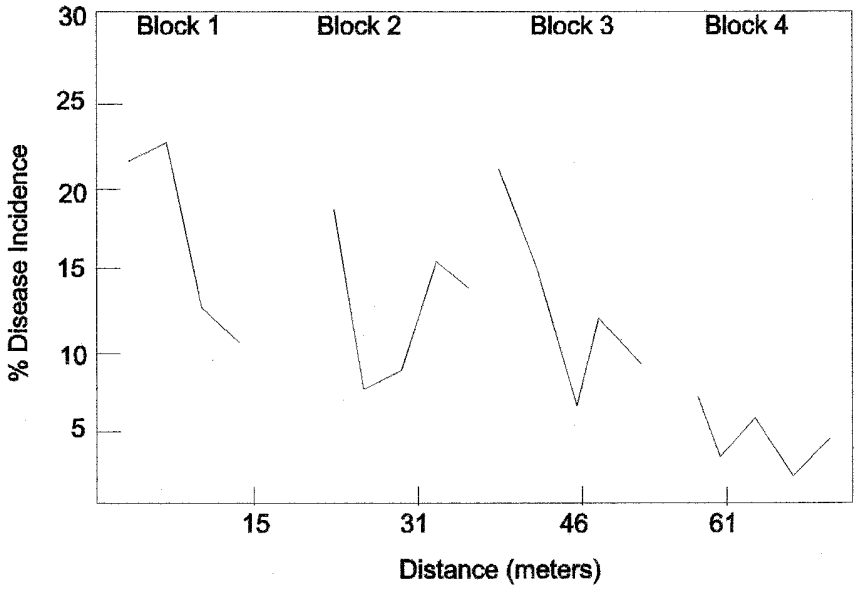

Fig. 2. Spatial distribution of final disease incidence in individual blocks of tomato transplant plots in southern Georgia in 1990.

Table 1. Chi-square analysis of ordinary runs (OR) and corrected doublets (CD) calculated from the final rating period in commercial fields or plots containing tomato spotted wilt virus–infected tomato, pepper, and tomato transplants from 1990 through 1992 in southern Georgia

					Chi-square values	
Year	**Location**	**Host**	**Cultivar**	**n[a]**	**OR**	**CD**
1990	BSF[b]	Tomato[c]	H-722	56	1.09	8.1
1990	ABAC Farm	Tomato	H-8245	54	0.42	8.1
1990	Cook Cty. A	Pepper	Marengo	84	185.00**[d]	1,633**
1990	Cook Cty. A	Pepper	Jupiter	204	53.20	634
1991	BSF-w	Tomato[c]	Ohio 7870	24	2.24	34.4
1991	BSF-c	Tomato[c]	Ohio 7870	32	1.09	3.3
1991	ABAC Farm	Tomato	H-7983	55	0.91	19.3
1991	Coffee Cty.	Pepper	Jalapeno	8	0.35	42.5**
1991	Coffee Cty.	Pepper	Yolo-L	108	1.70	50.2
1991	Coffee Cty.	Pepper	Jupiter	28	4.63	87.7**
1992	ABAC Farm	Tomato	Floridade	55	1.84	33.0

[a] n = number of rows in field.
[b] Blackshank Farm; w = western site and c = central site.
[c] Transplants.
[d] * and ** indicated significance at $P = 0.05$ and $P = 0.01$ levels, respectively.

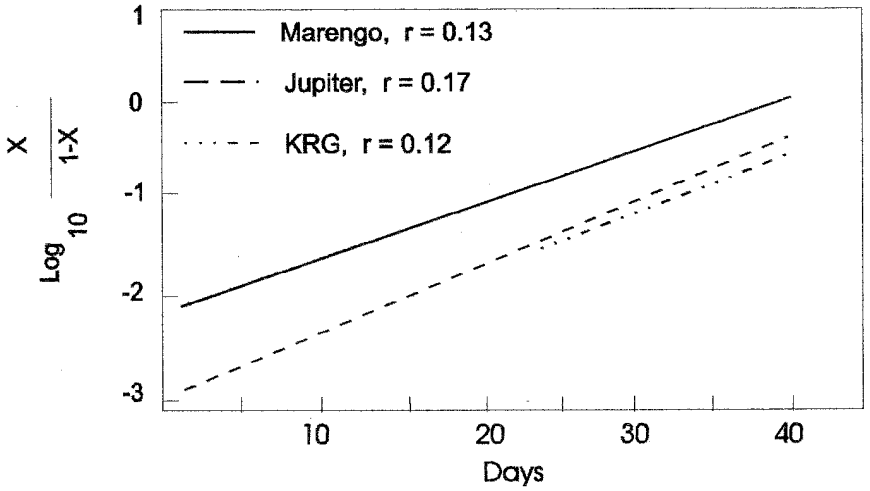

Fig. 3. Logit transformations of disease progress over time and basic infection rates (*r*) of tomato spotted wilt in three pepper cultivars in a commercial pepper field in Cook County in southern Georgia in 1990.

at the western site in 1990 or at either the western or central site in 1991 (Table 1). Although tospoviruses are mechanically transmitted (9,11), there was no evidence of mechanical transmission in the field within beds of plants receiving the clipping treatment. Likewise, there were no significant differences in amount of TSWV infections in clipped plants versus non-clipped plants in grow-out tests in the greenhouse. It is possible that the virus is not easily transmitted mechanically by the rapid clipping process, which clips the very apical end of the plant. Alternatively, infected plants may have been stunted sufficiently to have escaped the clipper's blades. In either case, the lack of aggregation and absence of transmission by clipping indicated that secondary transmission was inconsequential to TSW epidemics within transplants.

Furthermore, it indicated that TSW epidemics in production tomatoes grown from southern transplants were probably not from secondary spread by clipping but from primary inoculum from infested thrips and delayed expression from latent infections. In all cases, 100% of the plants identified as symptomatic by visual diagnosis gave a positive result for TSWV with ELISA.

In pepper at the Cook County site, the final disease incidences for Marengo, Jupiter, and Keystone Resistant Giant were 33, 21, and 14% of the plants, respectively, and were significantly different for the three cultivars ($P = 0.05$). However, a gradient emanated from the southwestern corner of the pepper field (Fig. 1B) with both a down-the-row and an across-the-field direction. The gradient, rather than cultivar reaction, probably accounted for the different disease levels because the basic infection rates for the three cultivars were not significantly different (Fig. 3), with Jupiter having the highest at $r = 0.17$. Furthermore, the primary gradient failed to flatten over time, which was most likely due to lack of secondary spread (7). Tests for aggregation were not significant except for the cultivar Marengo at the last rating period (Table 1). This probably was not due to aggregation caused by secondary spread, but rather by the high incidence of disease at the front of the gradient. In 1991 at the Coffee County site, there was a discrepancy between ordinary runs analysis (not significant) and corrected doublet analysis (significant at $P = 0.01$) for the aggregation of TSWV-infected pepper plants by the last rating period (Table 1). Madden et al. (10) concluded that corrected doublets produced unsatisfactory results when used to analyze simulations of generated random patterns, and that ordinary runs was superior for determining randomness of infected plants. Thus, we based our decision on the ordinary runs analysis and concluded that there was no significant aggregation of TSWV-

infected pepper plants at the Coffee County site.

There also were no disease gradients in the production tomato plots at the ABAC site in any year (1990 to 1992). Furthermore, both ordinary runs and corrected doublet analysis indicated no aggregation ($P = 0.05$) of TSWV-infected plants by the final survey date in any year (Table 1). Logistic transformations of disease progress curves for 1990 to 1992 are shown in Figure 4. The basic infection rates for the TSWV epidemics at the ABAC site were 0.10, 0.03, and 0.08 for 1990, 1991, and 1992, respectively. Yield reduction was significantly correlated with age of infection, with plants infected earlier in the season yielding fewer kilograms of fruit per plant (Fig. 5). Noninfected plants yielded 2.3, 1.7, and 1.75 kg of fruit per plant in 1990, 1991, and 1992, respectively. Yields were reduced by 50% if plants first displayed symptoms 24.5 days (3-year mean) prior to harvest. In 98% of samples, plants identified as symptomatic by visual diagnosis gave a positive result for TSWV with ELISA.

Madden et al. (10) indicated that spatial patterns of virus-diseased plants were influenced by many interacting factors, including environment and vectors, which resulted in a range of patterns. We observed gradients in tomato transplant beds when planted adjacent to TSWV-infected tobacco but not when beds were more than 200 m from tobacco plots. A gradient was observed in one pepper field but not in two others. Most likely the gradient observed at the Cook County site was due to a point source of inoculum close to the southwestern corner of the field. No gradients were observed in tomatoes at the ABAC site, where no other tomato, pepper, or tobacco was within a kilometer of the field plots, and the closest peanuts were 150 m from the site and planted after the first symptoms were observed on the tomatoes. This indicates that the source of inoculum was some distance (perhaps 200 m or greater) from the tomatoes.

Analysis of the spatial patterns of diseased plants in both transplants and production plots indicated that secondary spread was inconsequential to TSW epidemics in tomato. This is one reason why the basic infection rates were rather low. The fact that virus acquisition can only be accomplished by larvae and that only the adults transmit the virus is an integral reason for limited secondary spread. In order for infected plants to produce secondary inocula, thrips have to produce larvae that acquire the virus, pass through the incubation period, pupate, and migrate to healthy plants as viruliferous adults. The time required for these events and the interaction with insecticides would limit the amount of secondary spread. If transplants were moved to an area where the virus was not endemic and insecticides were used to reduce thrips already colonized on the transplant, losses should be less than if the plants were used locally, where they would be continuously exposed to inoculum.

Despite the limited secondary spread, TSW epidemics can be quite severe and can progress over time to account for enormous losses. We suspect the increased development of the disease is probably due to a continued influx of tremendous amounts of primary inoculum from viruliferous thrips. We also speculate that some disease observed later in the season is due to delayed development and symptom expression in some plants.

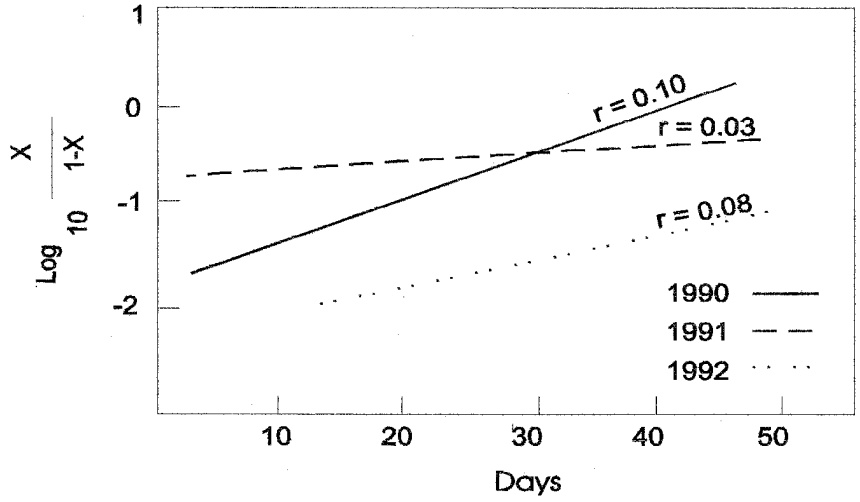

Fig. 4. Logit transformations of disease progress over time and basic infection rates (*r*) of tomato spotted wilt in tomato cultivars Heinz 8245, Heinz 7983, and Floridade in 1990, 1991, and 1992, respectively, in plots at the ABAC site in southern Georgia.

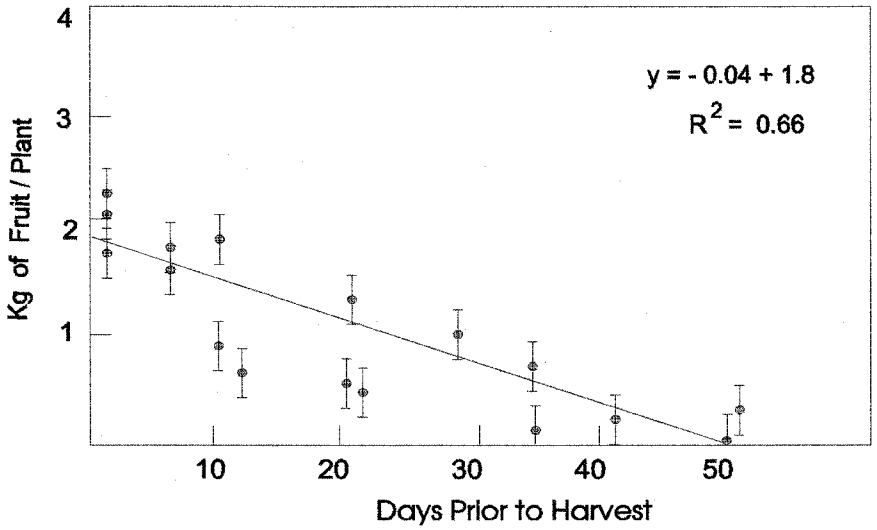

Fig. 5. Linear regression of fruit weight per individual plant (n = 20) versus time in days after first symptom expression of tomato spotted wilt in tomato cultivars Heinz 8245, Heinz 7983, and Floridade in 1990, 1991, and 1992, respectively. Bars represent standard error of the mean.

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LITERATURE CITED

1. Bald, J. G., and Samuel, G. 1931. Investigations on "spotted wilt" of tomatoes. II. CSIRO Australia Bull. 54.
2. Culbreath, A. K., Bertrand, P. F., Csinos, A. S., and McPherson, R. M. 1993. Effect of seedling source on incidence of tomato spotted wilt in flue-cured tobacco. Tob. Sci. 37:9-10.
3. Culbreath, A. K., Csinos, A. S., Bertrand, P. F., and Demski, J. W. 1991. Tomato spotted wilt virus epidemic in flue-cured tobacco in Georgia. Plant Dis. 75:483-485.
4. Culbreath, A. K., Csinos, A. S., and Brenneman, T. B. 1991. Association of tomato spotted wilt virus with foliar chlorosis of peanut in Georgia. Plant Dis. 75:863.
5. Culbreath, A. K., Todd, J. W., Gorbet, D. W., Branch, W. D., Sprenkel, R. K., Shokes, F. M., and Demski, J. W. 1996. Disease progress of tomato spotted wilt virus in selected peanut cultivars and advanced breeding lines. Plant Dis. 80:70-73.

6. Gitaitis, R., McCarter, S., and Jones, J. 1992. Disease control in tomato transplants produced in Georgia and Florida. Plant Dis. 76:651-656.
7. Gregory, P. H. 1968. Interpreting plant disease dispersal gradients. Annu. Rev. Phytopathol. 6:189-212.
8. Hobbs, H. A., Black, L. L., Story, R. N., Valverde, R. A., Bond, W. P., Gatti, J. M., Jr., Schaeffer, D. O., and Johnson, R. R. 1993. Transmission of tomato spotted wilt virus from pepper and three weed hosts by *Frankliniella fusca*. Plant Dis. 77:797-799.
9. Krishna Kumar, N. K., Ullman, D. E., and Cho, J. J. 1993. Evaluation of *Lycopersicon* germ plasm for tomato spotted wilt tospovirus resistance by mechanical and thrips transmission. Plant Dis. 77:938-941.
10. Madden, L. V., Louie, R., Abt, J. J., and Knoke, J. K. 1982. Evaluation of tests for randomness of infected plants. Phytopathology 72:195-198.
11. Matthews, R. E. F. 1970. Plant Virology. Academic Press, New York.
12. McHugh, J. B. 1991. Keep vegetable crops free of TSWV. Am. Veg. Grower 39:10-12.
13. Pitblado, R. E., Allen, W. R., Matteoni, J. A., Garton, R., Shipp, J. L., and Hunt, D. W. A. 1990. Introduction of the tomato spotted wilt virus and western flower thrips complex into field vegetables in Ontario, Canada. Plant Dis. 74:81.
14. Sakimura, K. 1962. The present status of thrips-borne viruses. Pages 33-40 in: Biological Transmission of Disease Agents. K. Maramorosch, ed. Academic Press, New York.
15. Steel, R. G. D., and Torrie, J. D. 1960. Principles of Statistics. McGraw-Hill, New York.
16. Ullman, D. E., Cho, J. J., Mau, R. F. L., Westcot, D. M., and Custer, D. M. 1992. A midgut barrier to tomato spotted wilt virus acquisition by adult western flower thrips. Phytopathology 82:1333-1342.
17. Vanderplank, J. E. 1946. A method for estimating the number of random groups of adjacent diseased plants in a homogeneous field. Trans. Roy. Soc. S. Afr. 31:269-278.
18. Vanderplank, J. E. 1963. Plant Diseases: Epidemics and Control. Academic Press, New York.