Yield/Quality Trade-Offs of Tobacco Mosaic Virus-Resistant Tobacco Cultivars in Relation to Disease Management

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ABSTRACT

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Field tests were conducted at two locations for 2 yr to quantify differences in flue-cured tobacco yield, quality, and value among tobacco mosaic virus (TMV)-resistant and -susceptible cultivars. Disease incidences (percent plants infected) were determined at a level at or above which resistant cultivars could be considered as a management option to reduce expected losses from planting susceptible cultivars. Incidence thresholds observed represented economic trade-off levels that may assist farmers in decisions regarding management of crop losses caused by TMV. Recently developed TMV-resistant cultivars had poorer leaf quality but produced as much or more yield and dollar income than most uninfected TMV-susceptible cultivars. Yields and values of a representative TMV-resistant cultivar were equivalent to that of a widely grown susceptible cultivar at TMV incidence levels in the susceptible cultivar of 13 and 37%. Using resistant cultivars could be recommended as the best tactic for managing tobacco mosaic when the incidence of the disease exceeds these levels. The apparent discrepancy between the yield and value thresholds was caused by reductions in leaf quality linked with the TMV resistance factor. Loss in quality could not be attributed solely to any single component of government tobacco grades or physical characteristic of flue-cured leaves.

Additional key words: crop loss assessment, modeling

Tobacco mosaic is an endemic disease of flue-cured tobacco in North Carolina caused by the tobacco mosaic virus (TMV). Estimates of annual disease losses in tobacco caused by TMV range from 0.03 to 0.088% (4,10). Because of the high value of flue-cured tobacco, TMV cost the farmers of this state an estimated $9.5 million in 1980 alone (10). Wolf and Moss (12), in early work, reported losses due to mosaic of 30 and 42% in yield and value, respectively. More recent research has determined that somewhat less severe losses occur, ie, 24% in yield and 29% in value (6). Control tactics recommended for TMV involve plant bed sanitation, roguing infected plants, rotation, washing field equipment, and use of resistant cultivars (7).

Commercial TMV-resistant cultivars restrict the virus to localized necrotic lesions that cause little or no damage to leaves. The genetic factor responsible for this resistance was transferred from *Nicotiana glutinosa* L. and incorporated into the contemporary TMV-resistant flue-cured tobacco cultivars (2,5).

Chaplin et al (3) noted that local lesion resistance to TMV adversely affected certain agronomic characteristics of the crop. Chaplin (1) concluded that using TMV-resistant cultivars would be economically advantageous only if infections occurred during the first half of the tobacco growing season. Chaplin and Mann (2) later suggested that, although breaking the linkage between the undesirable agronomic characters and the local lesion factor might be difficult, breeding work toward this goal should continue if use of resistant cultivars is to be considered seriously as a management tactic.

A number of recently released TMV-resistant cultivars have shown significantly improved yields and qualities over their predecessors. They are seldom planted, however, even though TMV continues to be a problem in commercial tobacco fields. We assume that this situation is a result of growers' perception of undesirable agronomic traits associated with the older TMV-resistant cultivars. County surveys estimated that about 0.015% of the flue-cured tobacco acreage in North Carolina was planted with TMV-resistant cultivars in 1979 (C. E. Main, *unpublished*).

The objectives of this study were 1) to quantify differences in yield, quality, and value among TMV-resistant and -susceptible cultivars under conditions of TMV versus no TMV and 2) to develop an econometric trade-off model to estimate the percent TMV incidence based upon an expected yield-quality-value response, above which TMV-resistant cultivars could be expected to return more profit to tobacco growers than the continued use of TMV-susceptible cultivars.

MATERIALS AND METHODS

Field experiments were conducted in 1980 and 1981 at the Border Belt Tobacco Research Station near Whiteville, NC, and the Upper Piedmont Research Station near Reidsville, NC.

Inoculum for the field tests was prepared and applied using methods similar to those of Gooding (4). A split-plot field design was used in 1980 with three and four replicates at Whiteville and Reidsville, respectively. Inoculation dates of 1, 5, 7, and 9 wk after transplanting of the crop were used as whole plots. Subplots were seven TMV-susceptible and three TMV-resistant tobacco cultivars. The 10 cultivars were randomized within each inoculation date.

Leaf area and number of leaves per plant were assessed weekly throughout the season. Four plants in each row were selected randomly and marked 3 wk after transplanting. Leaf area was assessed by measuring the length and width of one leaf in the bottom, middle, and top layers of each plant in the sample (9).

A split-split-plot experimental design was used in 1981 with seven replicates at each location. Cultivars served as whole plots, whereas subplots were composed of inoculation dates. Sub-subplots consisted of different incidences of TMV-infected plants. Border rows were placed between all treatments in both years. Weekly stand counts and visual disease assessments were made throughout the growing season in 1980 and 1981.

At the end of each season, weights and federal flue-cured tobacco grades were obtained for each plot (11). The value of each plot was then calculated using average market prices. Treatment differences in yield, value, and grade for each plot were analyzed by analysis of variance and the Waller-Duncan test. Further details of the experimental designs, methods of inoculum preparation and application, and most of the methods of analysis used, have been reported in another paper (6).

Linear regression analysis was used to determine economic threshold levels of

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the disease. A graphical representation of the trade-off model was obtained by overlaying the regression line for yield or value as a function of TMV incidence for a susceptible cultivar (McNair-944) with the regression line for a TMV-resistant cultivar (NC-628). The intersection of the two regression lines identified the yield or value "trade-off level." Above the trade-off level on the abscissa of the graph (TMV incidence), planting a TMV-resistant cultivar would be more advantageous than growing a susceptible one. Below the trade-off level, a TMV-susceptible cultivar would be recommended.

RESULTS

Although differences were noted among the reactions of the TMV-susceptible cultivars to TMV infection, no cultivar-treatment interactions were observed among the susceptible cultivars. Although losses in yield and value caused by TMV were generally greater at Reidsville than at Whiteville, no cultivar-location interactions occurred.

The more recently released resistant cultivars produced as much or more yield and resulted in dollar values equal to or better than those of the susceptible cultivars in uninfected plots (Tables 1 and 2). In our 1980 tests, the TMV-resistant cultivar Coker-86 produced the highest yield and value of all cultivars. McNair-944, a TMV-susceptible cultivar, produced the second largest yield and value, followed by another TMV-resistant cultivar, NC-628. The old-line TMV-resistant cultivar VA-770 showed the lowest yield and value even when compared with the TMV-infected cultivars. Differences in yield, average grade index, and value were detected among infected as well as uninfected susceptible cultivars. Yield losses among TMV-infected cultivars were equivalent, but losses in average grade index and dollar value differed (Table 2; Figs. 1 and 2).

The TMV-resistant cultivar NC-628 outyielded and produced more income than even the controls for the TMV-susceptible cultivar NC-2326 in 1981. Among plots of McNair-944 inoculated 35 days after transplanting, treatments of 15% TMV incidence outyielded and generated more income than NC-628 (Figs. 1–4). All plots of TMV-susceptible McNair-944 inoculated with TMV 7 days after transplanting produced lower yields and values than did those of NC-628 (Figs. 1 and 2). The trade-off model indicated that the threshold level for yield was 13% TMV incidence, whereas 37% incidence was the trade-off level for dollar value (Figs. 3 and 4).

Regression equations were developed to describe the relationship between value and TMV incidence for resistant and susceptible cultivars:

$$VR = 1,694 \quad (1)$$

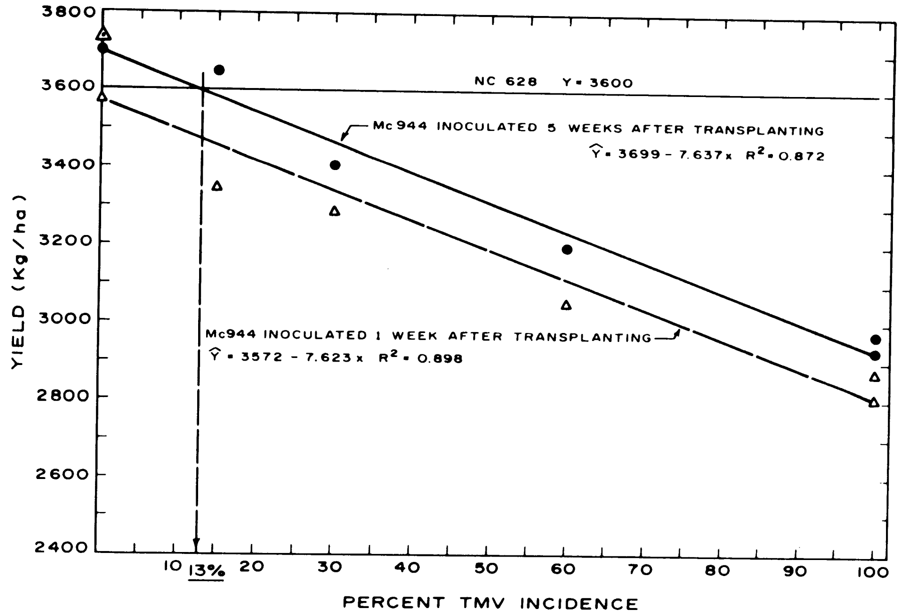

Fig. 1. Yield versus incidence of tobacco mosaic virus for McNair-944 at Whiteville, NC, in 1981.

Table 1. Agronomic characters of 10 flue-cured tobacco cultivars in the absence of tobacco mosaic virus (TMV) in 1980[y]

Cultivar	Yield (kg/ha)	Value ($/ha)	Grade index[z]	Leaf area (mm^2)	Leaves (no.)
TMV-susceptible					
McNair-944	2,817 bc	1,518 bc	38.11 ab	119,352 b	18.36 ab
NC-744	2,816 bc	1,408 c	24.64 c	120,192 b	15.97 bc
NC-2512	2,744 bc	1,454 bc	32.61 bc	124,534 b	17.84 ab
NC-2326	2,671 c	1,442 bc	38.91 ab	118,877 b	17.91 ab
NC-82	2,663 c	1,473 bc	48.13 a	117,289 b	18.02 ab
NC-95	2,645 c	1,401 c	34.96 bc	117,804 b	18.19 ab
SpC-28	2,621 c	1,412 c	46.71 ab	116,701 b	18.93 a
TMV-resistant					
Coker-86	3,308 a	1,704 a	29.01 bc	137,683 a	19.09 a
NC-628	2,973 b	1,500 ab	35.63 bc	124,144 a	18.00 ab
VA-770	2,581 c	1,371 c	36.11 bc	122,004	17.25 bc
Waller-Duncan LSD *k*-ratio = 100	265	159	11.89	13,390	1.33

[y]Results are means for two locations with three replicates at one site and four replicates at the other site.
[z]A 0-99 index of federal flue-cured tobacco grades (11) that reflects some aspects of tobacco quality.

Table 2. Losses in yield, value, and quality for each susceptible cultivar tested

Cultivar	Yield loss (%)	Loss in value (%)	Loss in quality (%)[z]
1980			
McNair-944	14.85 a	16.53 ab	9.02 cd
NC-744	14.30 a	18.25 a	26.99 a
NC-2512	11.21 a	15.94 ab	22.18 ab
NC-2326	12.90 a	14.01 ab	9.58 cd
NC-82	11.52 a	12.36 b	5.53 d
NC-95	13.01 a	15.73 ab	17.10 bc
SpG-28	14.80 a	16.24 ab	6.74 d
Waller-Duncan LSD *k*-ratio = 100	4.59	4.91	
1981			
McNair-944	22.50 a	18.22 a	15.76 b
NC-2326	18.68 a	13.47 a	25.60 a
Waller-Duncan LSD *k*-ratio = 100	6.12	6.53	

[z]Quality was measured using a 0–99 index of federal flue-cured tobacco grades (11).

$$VS = 1{,}856 - 4.602X \quad r^2 = 0.985, \qquad (2)$$

where VR and VS equal the value ($/ha) of a resistant and susceptible cultivar, respectively, and X is TMV incidence following infection 35 days after transplanting. Equation 2 was subtracted from equation 1 to determine the difference in value between the resistant and susceptible cultivars at any given incidence:

$$VC = 4.602X - 171, \qquad (3)$$

where VC equals the cost associated with deciding whether to use a TMV-resistant or susceptible cultivar and X equals TMV incidence.

Inoculation 7 and 35 days after transplanting reduced leaf area per plant compared with the control plots (6). Inoculations after 35 days had no effect. The mean area of individual leaves was reduced only by inoculation 35 days after transplanting. The number of leaves per plant in plots inoculated 7 days after transplanting differed from those of all other plots as did the number of leaves measured in the control plots. The newer TMV-resistant cultivars showed larger total leaf areas per plant than did the TMV-infected susceptible lines.

DISCUSSION

Disease management tactics are often evaluated by direct comparison of a single level of disease with one or more disease-control treatments. Such tests cannot adequately describe the relationship between the range of disease levels growers may encounter and the ensuing crop losses resulting from these different levels. Because treatment costs are seldom considered, test results are not analyzed to account for the various costs involved. These test designs can identify disease control measures that are consistently beneficial under standard conditions but could overlook disease management options that show desirable results in some situations but not in others.

Our approach was similar to that used by Norton (8) for defining an economic threshold to control the potato cyst nematode by using dichloropropane-dichloropropene. In our study, losses in yield and value caused by TMV were quantified over a range of disease incidences and these losses were characterized as damage functions. We compared these functions with possible yield and value losses associated with TMV resistance to formulate an econometric trade-off model. The model was further generalized for wider application by using percent reductions to describe loss rather than actual yield and value numbers as the dependent variables (Figs. 4 and 5).

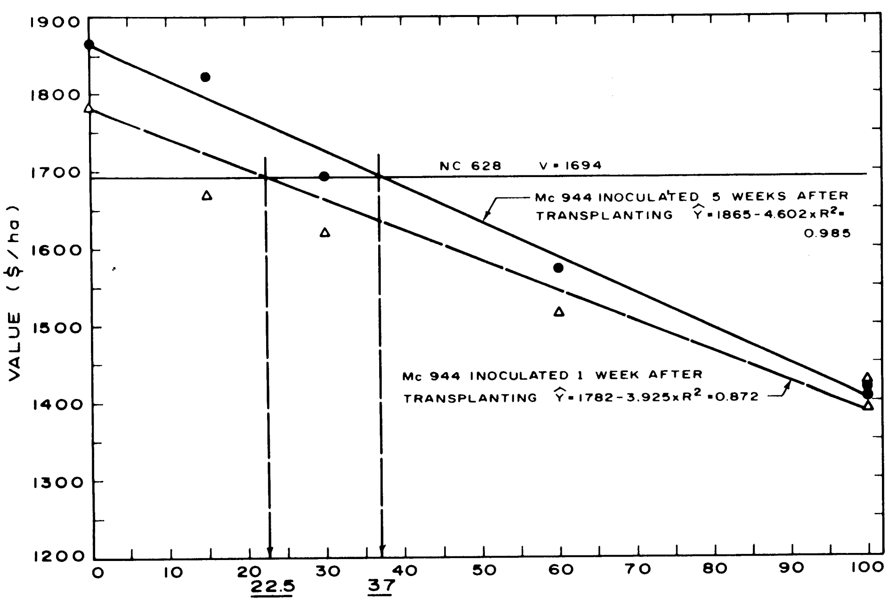

Fig. 2. Value versus incidence of tobacco mosaic virus for McNair-944 at Whiteville, NC, in 1981.

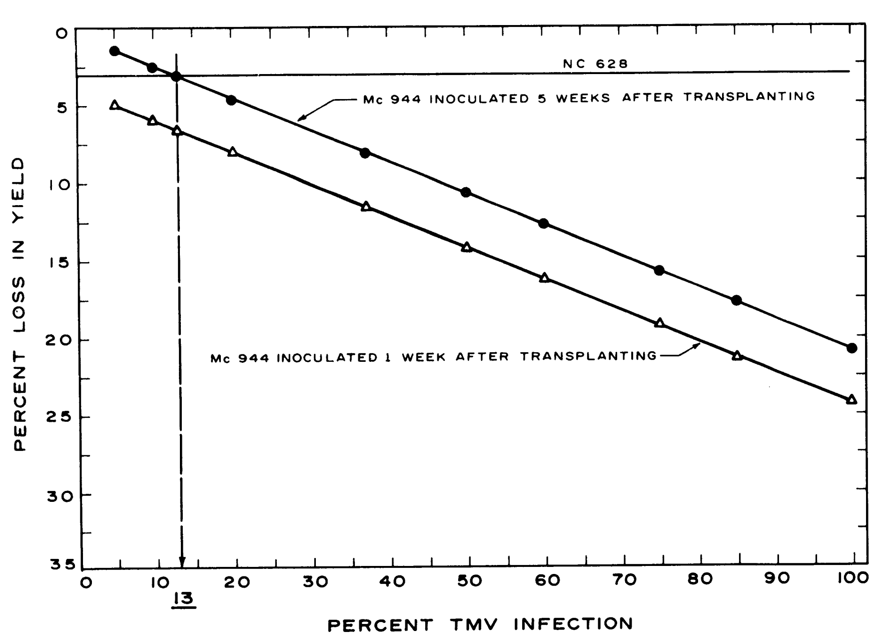

Fig. 3. Percent loss in yield versus incidence of tobacco mosaic virus for McNair-944 at Whiteville, NC, in 1981.

Econometric trade-off models identify disease thresholds that could help growers decide when and where to use resistant cultivars as an alternative to other control measures. Another use of such models is to estimate the cost of making the wrong pest management decisions, ie, how much income or yield may be lost if some suboptimal control measure is chosen. This cost is simply the difference in yield or income between the tactic employed and an optimal tactic. Such costs are relatively easy to calculate, as illustrated in Figure 5 and Table 3. Estimates of such costs are useful for making once-a-year disease management decisions on cultivar preference or, in the more common situation, where pest attack level is uncertain.

Table 3 was generated from equation 3 and gives the relative costs of planting a TMV-resistant cultivar versus a susceptible cultivar when disease incidence will be below the trade-off level by various levels of incidence. These costs (losses) are virtually the same for planting a TMV-susceptible cultivar versus a resistant cultivar when disease incidence exceeds the threshold value by an equivalent level of incidence. The maximum possible loss from planting a resistant cultivar unnecessarily ("B" in Fig. 5) is about one-third of the maximum possible loss due to 100% TMV incidence ("E" in Fig. 5). These estimates of the cost of a wrong decision ("H"–"I" or "J"–"J'") allow the grower to consider his potential loss when making such a risky choice.

The large difference between the trade-off levels obtained for yield and for value ("L" in Fig. 5) reflects the effect of the

TMV resistance factor on tobacco quality. The trade-off level for yield was low because the resistant cultivar showed comparatively high yields, ie, the TMV resistance factor had no deleterious effect on yield. The resistant cultivar, however, still possessed some inferior leaf qualities that reduced its market value. This loss in value resulted in an economic trade-off level at a higher incidence of the disease than that obtained for yield alone.

The results of this investigation show that TMV affects the yield and value of selected susceptible cultivars in a similar manner. Although susceptible cultivars differed in quality, differences in value generally were not significant. The model should, therefore, apply to most currently available TMV-resistant and susceptible cultivars.

As a general rule, resistant cultivars should present an economical alternative when 1) recommended sanitation practices have been followed (10) but TMV still infects 37% or more of the plants in the crop, and 2) land or costs of rotation are production constraints. Crop (spatial) rotation has traditionally been recommended in such cases. Use of TMV-resistant cultivars may be viewed as a different form of the same approach to the management of this disease. Resistant cultivars may be planted for 1 or 2 yr so that while a field would be in continuous tobacco culture, susceptible cultivars would be rotated with resistant cultivars.

The economic evaluation of crop (spatial) versus cultivar (temporal) rotation as a disease management tactic would require further study before being considered as another component of any management trade-off model. The costs of spatially rotating tobacco with other less valuable crops probably exceed those of planting a TMV-resistant cultivar with slightly poorer leaf quality. In addition, many tobacco growers do not have the necessary land to rotate their tobacco crop. From a practical and economic standpoint, resistant-susceptible cultivar rotation would be superior to crop rotation for control of TMV in flue-cured tobacco. A grower should plant a TMV-resistant cultivar if he expects, based on past experience, that his field(s) will have 37% or more TMV incidence in the coming season.

Tobacco virus surveys conducted in North Carolina in 1978, 1979, and 1981 detected TMV incidence at or above the trade-off level in 6, 9, and 3% of the fields observed, respectively (G. V. Gooding, *unpublished*). Comparisons of these figures with the percentage of the North Carolina flue-cured tobacco crop acreage presently planted to TMV-resistant cultivars (0.015%) indicate that resistant cultivars are not being utilized optimally. Three to 9% of the fields in the state should probably be planted with a resistant cultivar in order to optimally reduce tobacco crop losses caused by TMV.

The loss in cured leaf quality caused by the TMV resistance factor could not be attributed to any single component of the federal grades that influence market value and determine the support price of flue-cured tobacco. Losses in cured leaf quality

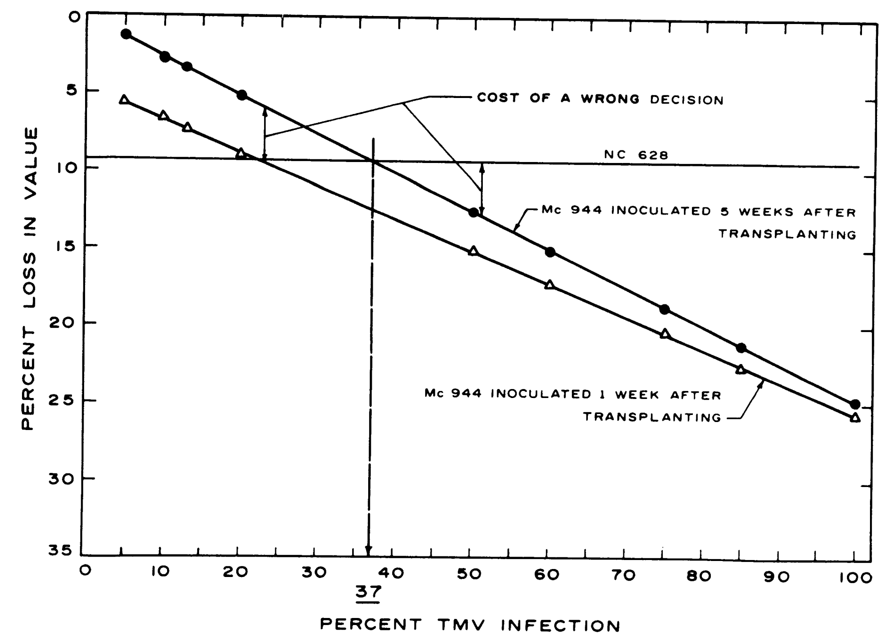

Fig. 4. Percent loss in value versus incidence of tobacco mosaic virus for McNair-944 at Whiteville, NC, in 1981.

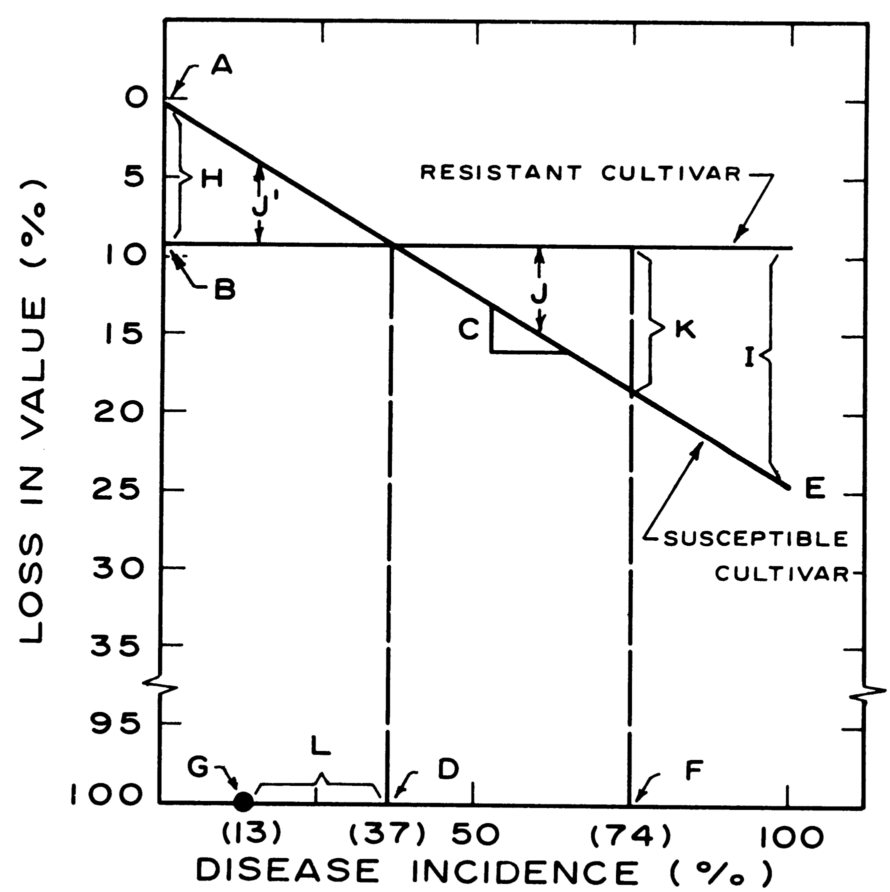

Fig. 5. Generalized tobacco mosaic virus resistant cultivar trade-off model. A = Value of susceptible cultivar (SC) in absence of disease, B = value of resistant cultivar (RC) across all incidences, C = slope of regression for SC on incidence (−4.602), D = trade-off threshold, ie, value of SC and RC equivalent, E = value reduction for SC at 100% incidence, F = incidence at which loss due to wrong decision to plant RC (disease absent) equivalent to wrong decision to plant SC (disease present), G = yield trade-off threshold, ie, yield of SC and RC equivalent, H = difference in value between RC and SC at 0 incidence, I = difference in value between RC and SC at 100% incidence, J and J′ = difference in value between RC and SC at incidences x_i and x_i', K = percent loss in value for SC equivalent to planting RC in absence of disease, and L = difference between yield and value trade-off threshold levels, ie, the effect of disease on quality per se.

Table 3. Trade-off computations using actual data collected for McNair-944 at Whiteville, NC, in 1980–1981[a]

Tobacco mosaic incidence (%)	Differences between resistant and susceptible cultivars		Differences between infected and uninfected susceptible cultivars	
	Yield (kg/ha)	Value ($/ha)	Yield (kg/ha)	Value ($/ha)
0	−99	−171	...	...
5	−61	−148	−38	−23
7	−46	−139	−53	−32
10	−23	−125	−76	−46
13[b]	0	−111	−99	−60
16	+23	−97	−122	−74
19	+46	−84	−145	−87
20	+54	−79	−153	−92
21	+61	−74	−160	−97
30	+130	−33	−229	−138
37[c]	+183	0	−283	−171
44	+237	+31	−336	−202
54	+313	+78	−412	−249
64	+390	+124	−489	−295
74	+466	+170	−565	−341
85	+550	+220	−648	−391
100	+665	+289	−746	−460

[a] Given that the mean yield for McNair-944 uninfected with TMV was 3,966 kg/ha with a value of $1,865/ha and that the mean yield for NC-628 was 3,600 kg/ha with a value of $1,694/ha.
[b] Threshold level for yield.
[c] Threshold level for value.

were found to result from increases in the variability of stalk positions, quality ratings, and colors. Increases in the variability of these components of federal grades were also observed in TMV-infected tobacco, particularly an increase in the proportion of green, or immature, classes of cured leaf.

Further research on the effects of various environmental and cultural factors on tobacco mosaic will be necessary to predict the incidence of this disease in an objective and quantitative manner. Data would have to be collected from a large set of fields over at least 3 yr, preferably more. Given such probabilities of incidence based on pattern and extent of pathogen spread, soil type, soil moisture, winter air temperatures, crop rotation, alternate hosts, tillage practices, and tobacco cultivar, an evaluation of TMV-directed sanitation practices could be attempted. This knowledge would greatly increase the usefulness and test the validity of the crop loss assessment model(s) for TMV in flue-cured tobacco.

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