Effects of Two-Year Crop Rotations and Cultivar Resistance on Bacterial Wilt in Flue-Cured Tobacco

T. A. MELTON, Assistant Professor, and N. T. POWELL, Professor Emeritus, Department of Plant Pathology, North Carolina State University, Raleigh 27695

ABSTRACT

Melton, T. A., and Powell, N. T. 1991. Effects of two-year crop rotations and cultivar resistance on bacterial wilt in flue-cured tobacco. Plant Dis. 75:695-698.

The incidence of bacterial wilt, caused by *Pseudomonas solanacearum*, was reduced and the yield of flue-cured tobacco (*Nicotiana tabacum*) was increased by cultivar resistance and by 1-yr rotation to corn, fescue, or soybeans as compared with continuous tobacco. In general, crop value and yield were higher and disease index lower when tobacco was grown after soybeans than after fescue, corn, or tobacco. The value, yield, and disease index for tobacco grown after corn and after fescue did not differ. In contrast, value and yield were lowest and disease index was highest for continuous tobacco. The rotation used had a greater effect on the disease index in the more susceptible of the three tobacco cultivars planted. The disease index was 2.7–4.8 times higher in the more susceptible cultivar, whereas yields were 1.1–2.3 times higher in 2 of the 3 yr for the more resistant cultivar. When plots were fumigated with 1,3-dichloropropene + chloropicrin, yield was 8.4% higher but the disease index was not affected.

Additional keywords: Granville wilt

Bacterial wilt, caused by *Pseudomonas solanacearum* E. F. Smith, also known as Granville wilt, is one of the most devastating diseases of flue-cured tobacco (*Nicotiana tabacum* L.) in the United States. Losses in 1988 totaled $11.5 million (0.87% of the U.S. crop), of which $11 million (1.16% of North Carolina crop) was incurred in North Carolina (6). Losses in North Carolina during the past 5 yr have averaged $10.9 million per year (1.28% of the crop value) (13). Bacterial wilt initially appeared in Granville County, North Carolina, and surrounding counties in the middle belt about 1880. Since then, it has spread throughout most of North Carolina, to part of South Carolina, to many other major tobacco-growing countries in warm-temperate and semitropical areas (9,11), and, most recently, to South Africa (3).

The disease is most prevalent and damaging in fields that are planted continuously to tobacco and where soil moisture is high to excessive. High temperatures also favor survival of the organism (1), as evidenced by the absence of the disease in areas where midwinter mean temperatures are below 10 C (11).

Nonhost crops in rotations with tobacco have been used to manage bacterial wilt (4,10,15). Recommendations from these studies included 3- to 5-yr rotations and the use of resistant cultivars. A combination of rotation to nonhost crops, cultivar resistance, and fumigation with 1,3-dichloropropene + chloropicrin or with chloropicrin alone is the recommended management system for bacterial wilt in North Carolina (12). Short-term rotation, resistance, or fumigation alone does not suppress bacterial wilt sufficiently. Data are lacking for the effects of nonhosts on wilt severity and crop yield in 2-yr rotations. The high cash value of tobacco compared with the value of alternate field crops and the limited availability of farmland suitable for tobacco production are often given as reasons why rotations rarely exceed 2 yr. The long rotation needed to control bacterial wilt adequately is an important limitation (14).

In the research described here, four 2-yr rotations were tested through three cycles (6 yr) for control of bacterial wilt in tobacco. Effects of cultivar resistance and fumigation (1 yr) also were tested. Disease incidence, disease index, tobacco yield, and value were measured.

MATERIALS AND METHODS

The field (on the Kelvin Bass farm in Nash County, North Carolina) was Norfolk loamy sand, 2–6% slope (fine loamy, siliceous, thermic, Typic Paleudults) in the Upper Coastal Plain. In 1982, tobacco was grown throughout the field, and losses due to bacterial wilt exceeded 25%. The diagnosis was based on unilateral wilting, discolored streaks in the vascular system of the stem, and microscopic observation of a bacterial ooze streaming from the vascular tissue taken from the stem. Unilateral wilting was followed by general wilting, yellowing, and finally death.

In 1983, 1985, and 1987, tobacco, fescue (*Festuca* sp.), corn (*Zea mays* L.), and soybeans (*Glycine max* (L.) Merr.) were planted in eight-row plots, 1.2 m apart and 13.7 m long. The crops were grown to maturity, harvested, and/or disked into the soil. Fescue stands were generally poor (10–25%), resulting in partial weed fallows with ragweed (*Ambrosia artemisiifolia* L.) and crabgrass (*Digitaria* sp.) predominating. During all 6 yr, tobacco plots were split with four rows of a highly resistant cultivar (K 399) and four rows of a slightly resistant cultivar (McNair 944). The plots were arranged in a split-plot, randomized complete block design with four replications. During the even years (1984, 1986, 1988), tobacco was grown in the entire test. During the last rotational cycle, the moderately resistant cultivar K 326 was substituted for the slightly resistant McNair 944. Tobacco cultivars were not rotated from plot to plot, so their field locations remained constant. Each year, the crop was planted in the same rows as the previous years. During 1988, subplots were further split to two two-row sub-subplots with and without 98.2 L/ha of the soil fumigant 1,3-dichloropropene + chloropicrin (Telone C-17) applied after bedding with a gravity-flow, single-point injector 35 cm deep.

The field was fertilized with 77–83 kg/ha of nitrogen, 60–83 kg/ha of phosphorus, and 114–224 kg/ha of potassium, as suggested by the soil testing laboratory. The soil pH was 5.7–6.1. The grower transplanted according to normal and accepted practices for the area and was supervised by university personnel. Transplanting dates were late April 1984, 26 April 1986, and 4 May 1988. Plots were hand-harvested four times in 1984 and 1986 and three times in 1988, and leaves were cured in a bulk curing barn. U.S. government grades were assigned to each harvest of each plot, and a price per 100 kg was assigned based on the average price paid during the year for that grade.

Initial stand counts, disease incidence, vigor ratings, disease index, yield (kilograms of cured leaf), price ($/100 kg), and crop value ($/ha) were recorded. Disease incidence was recorded at 2- to 3-wk intervals beginning when disease was first observed. A plant was considered diseased only when advanced symp-

Use of trade names does not imply endorsement by the North Carolina Agricultural Research Service of the products named or criticism of similar ones not mentioned.

Accepted for publication 18 December 1990.

Table 1. Effects of previous crop(s) on flue-cured tobacco value, yield, and disease index in a field with a history of severe losses to bacerial wilt[y]

	1984			1986			1988		
Previous crop	Value ($/ha)	Yield (kg/ha)	Disease index	Value ($/ha)	Yield (kg/ha)	Disease index	Value ($/ha)	Yield (kg/ha)	Disease index
Soybean	10,875 a[z]	2,830 a	5.7 b	7,611 a	2,128 a	18.3 b	11,821 a	3,177 a	4.8 b
Corn	10,860 a	2,813 a	6.7 ab	6,509 b	1,800 b	25.0 b	10,959 a	2,904 b	7.6 b
Fescue	10,847 a	2,837 a	4.6 b	6,400 b	1,747 b	24.6 b	11,115 a	2,941 b	7.1 b
Tobacco	9,845 a	2,572 a	8.4 a	3,327 c	916 c	55.0 a	8,698 b	2,315 c	12.4 a
CV (%)	10.1	10.6	48.2	13.7	15.1	21.7	10.7	10.2	47.6
R^2	0.72	0.68	0.87	0.97	0.97	0.77	0.85	0.86	0.89

[y] Data for 1984 and 1986 are means of two cultivars and four replications, and data for 1988 are means of two cultivars, 1,3-dichloropropene + chloropicrin treatment and no treatment, and four replications. Disease index is calculated as $DI = \Sigma_{i=1}^{n} X_i\,[100 - (i - 1)(100/n)]/I$, where i = ordinal evaluation number, X = number of diseased plants since previous count, n = number of evaluations, and I = initial number of plants in the plot.

[z] Means followed by the same letter within columns are not different according to Duncan's multiple range test ($P = 0.05$).

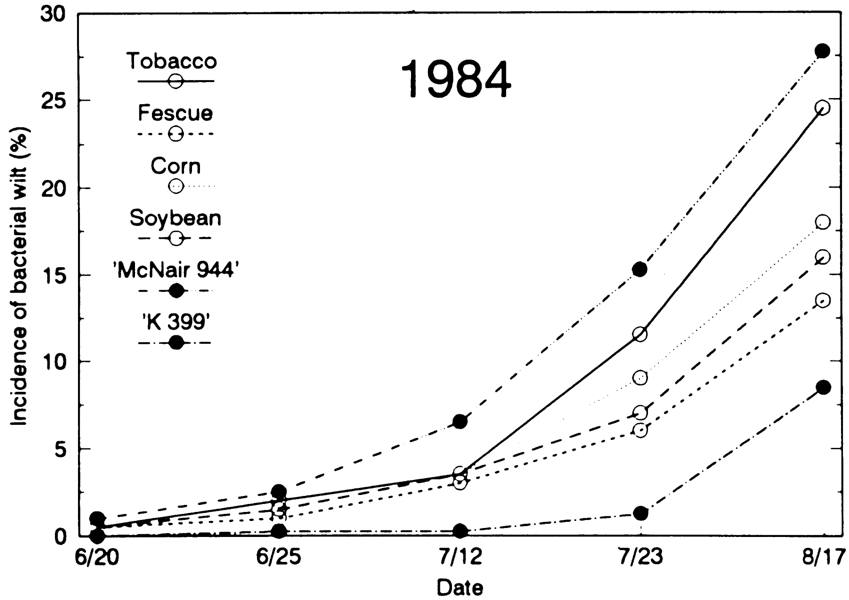

Fig. 1. Progress in 1984 of bacterial wilt in tobacco rotated with tobacco, fescue, corn, or soybean is averaged over two cultivars (McNair 944 and K 399) with four replications. Disease progress for cultivars is averaged over the four crop rotations with four replications each.

toms of wilt were evident. A disease index was calculated from disease incidence and date (2) and weighted such that plots with high disease incidence early had higher disease indices than those that were infected later, even if the final incidence was the same. Vigor ratings were subjective attempts to quantify growth on a scale of 0-100, with 100 being best. The disease index reflected both disease incidence and time of disease onset. All data were subjected to ANOVA, and multiple means were separated using Duncan's new multiple range test ($P = 0.05$). Selected orthogonal contrasts were made.

RESULTS

Effects of crop rotation on tobacco vigor, value, and yield. In 1984, no significant differences ($P = 0.05$) were observed among the rotations for value, yield, or quality of tobacco (Table 1). Although tobacco yield was 9.4-10.3% higher in the rotated treatments than in continuous tobacco, orthogonal contrasts were not significant. On 26 June, vigor ratings were highest for plots rotated with corn (68) and lowest for continuous tobacco (54.5). On 17 August, however, vigor ratings were highest on plots rotated with fescue (65.5) and lowest on those rotated with soybean (60.5).

Disease was more severe in 1986 than in the other years, causing greater differences in value and yield among the treatments (Table 1). On 11 June, vigor ratings were higher for corn (67) and fescue (64) and lower for soybeans (58) and tobacco (56.5). By 6 August, vigor ratings were greatly influenced by the incidence and severity of bacterial wilt. Fescue (63) and soybean (63) rotations were rated highest, corn (58) was moderate, and tobacco (37) was lowest.

Disease severity was moderate in 1988, resulting in a yield difference of 862 kg/ha between continuous tobacco and tobacco rotated with soybean. Quality was affected significantly ($P = 0.05$) only in 1988, when tobacco rotated with soybean was reduced by $3.57/100 kg compared with continuous tobacco, which was of the next lowest quality. However, the increased yield, associated with the soybean rotation, more than compensated for reduced quality. All vigor ratings on 2 June were nearly equal, with plants in the soybean (61.5) rotation being highest and those in the continuous tobacco (57.7) lowest. On 25 July, however, vigor ratings among the rotations were notably different: soybean 78.5, fescue 70, corn 66, and tobacco 64.2. No significant crop × cultivar interactions occurred for value, yield, or quality during any of the years.

Effects of crop rotation and cultivar resistance on disease. In 1984, the disease index was significantly higher for continuous tobacco than for soybean or fescue rotations (Table 1). Disease incidence remained relatively low, and differences among crop rotations did not appear until 23 July (Fig. 1). Those differences remained relatively constant through harvest. Disease incidence increased most rapidly from the second to fourth harvest.

In 1986, the disease index was significantly higher for plants in the continuous tobacco treatment than for those in rotations. A significant previous crop × tobacco cultivar interaction occurred and was the only interaction between previous crop and cultivar during any year. Differences ($P = 0.05$) in disease index between cultivars (McNair 944 vs. K 399) were greatest where tobacco preceded tobacco (75.8 vs. 29.3), moderate where tobacco rotated with corn (42.3 vs. 7.7), and lowest where tobacco rotated with fescue (37.4 vs. 10.2) or soybean (31.5 vs. 5.0). The disease index on McNair 944 in rotation with soybean was nearly equal to that of the nonrotated K 399 in the continuous tobacco rotation. Differences in incidence among rotations were evident by 11 June, peaked between 23 June and 10 July, and remained relatively constant through harvest (Fig. 2).

The disease index was lower in 1988 than in 1986, but differences among rotations were similar. Disease incidence increased most rapidly from disease detection to 12 July and generally peaked by 25 July (Fig. 3). In each of the 3 yr, the cultivar with less resistance had a significantly ($P = 0.01$) higher disease index and faster disease development than the other cultivar.

Effects of cultivar on tobacco vigor, value, and yield. In 1984, no significant differences occurred between McNair 944 and the highly resistant K 399 (Table 2). However, the yield of K 399 exceeded that of McNair 944 by 9.4%. Vigor ratings for the two cultivars were nearly equal. In 1986, the yield of K 399 was more than double that of McNair 944. Vigor ratings on 11 June were 65.5 for McNair 944 and 57.2 for K 399. On 6 August, ratings were 44.5 for McNair 944 and 63.2 for K 399. The McNair 944 vigor rating of 14 in the continuous tobacco was particularly low. In 1988, the moderately resistant K 326 did not differ significantly from K 399 in value or yield. However, the quality of K 326 was significantly greater than that of McNair 944, resulting in a value increase of $445/ha. Vigor ratings were slightly higher for K 326 than for McNair 944 throughout the season.

Effects of fumigation in 1988. Fumigation significantly increased yield by 228 kg/ha and value by $875/ha. No differences were detected in disease incidence index, however. Significant ($P = 0.01$) fumigation × previous crop and fumigation × cultivar interactions occurred for crop value. Fumigation increased value more when nonhost crops were in the rotations than when tobacco was continuous. A significant ($P = 0.05$) fumigation × cultivar interaction occurred for yield. Fumigation increased value and yield more for the highly resistant cultivar than for the moderately resistant one.

DISCUSSION

About 50% of the flue-cured tobacco in North Carolina is grown in a 2-yr rotation and about 15% is grown in continuous culture (13). Higher quotas (total pounds per farm), larger tobacco revenues, and a limited number of suitable fields are causing growers to plant continuous tobacco more often. Because bacterial wilt and other soilborne and residue-borne diseases are unpredictable, growers are often willing to accept the risk of disease to produce their quota on their "best tobacco land." Profits from tobacco are much higher than those from other field crops, so growers will always plant enough tobacco to ensure their quota.

The direct economic benefits of a 2-yr rotation, resistant cultivars, or fumigants are difficult to measure. An unused quota in a single year may be used another year or leased. If losses are expected each year, however, more acreage must be planted to fulfill the quota. When acreage is increased because of expected lower yields, production costs per pound of quota increase and revenue that might be derived from other crops is lost. However, if we assume that growers did not carry forward or lease unused quotas and that the acreages of tobacco and soybeans grown were equal, a grower who rotated tobacco with soybeans in that field from 1984 through 1988 would have net revenues from tobacco and soybeans of $31,591/ha, compared with only $9,254/ha if tobacco and soybeans each had been grown continuously. This difference may be grossly exaggerated, as it depends on how well the grower can estimate the area needed to produce his quota and on how well he can market his quota. These estimates assume $173/ha net revenue from soybeans, whether rotated or not, and $3,954/ha production costs for tobacco. If the field was fumigated, the difference would likely be larger. If a resistant cultivar was used, however, the difference may be smaller, based on our 1986 data and those of Smith (15), who showed that the previous crop did not reduce disease as much if highly resistant tobacco lines (TI 448A and 79X) were grown. Others (4,10,15) have reported the negative effects of growing tobacco continuously in a field. The similarities in data between the fescue and corn rotations in our study somewhat support those of Garner et al (4), who reported that for tobacco planted after 5 yr of

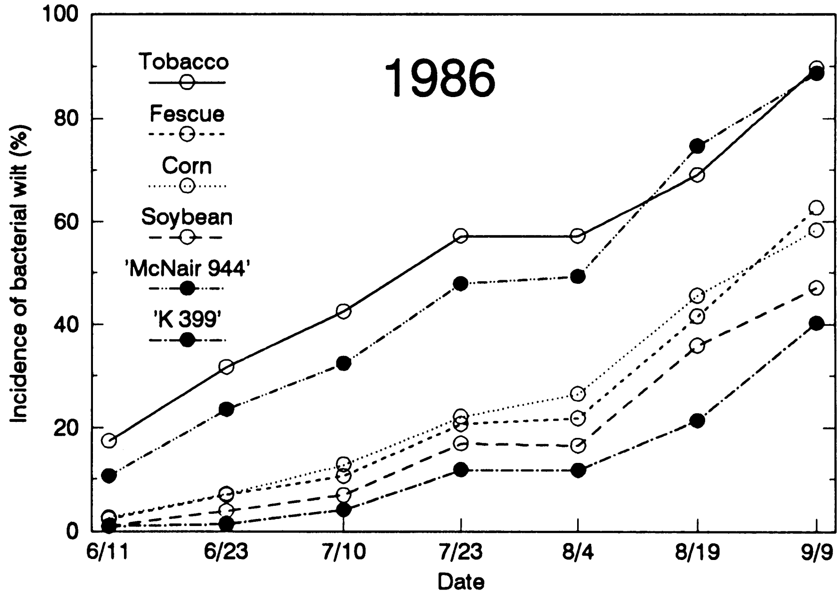

Fig. 2. Progress in 1986 of bacterial wilt in tobacco rotated with tobacco, fescue, corn, or soybean is averaged over two cultivars (McNair 944 and K 399) with four replications. Disease progress for cultivars is averaged over the four crop rotations with four replications.

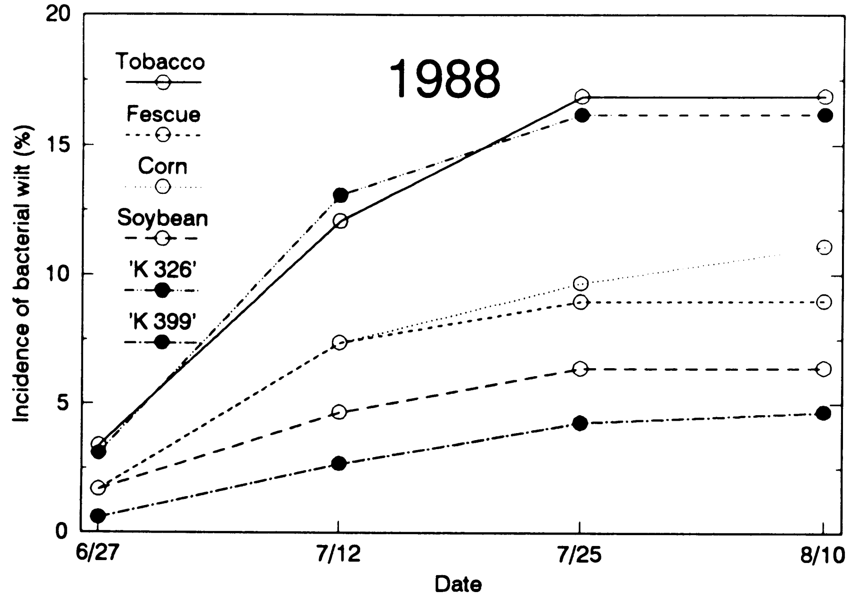

Fig. 3. Progress in 1988 of bacterial wilt in tobacco rotated with tobacco, fescue, corn, or soybean is averaged over two cultivars (K 326 and K 399) and fumigated and nontreated plots with four replications. Disease progress for cultivars is averaged over the four crop rotations and fumigated and nontreated plots with four replications.

Table 2. Effects of cultivars on flue-cured tobacco value, yield, and disease index in a field infested with *Pseudomonas solanacearum*[x]

Tobacco cultivar[y]	1984 Value ($/ha)	1984 Yield (kg/ha)	1984 Disease index	1986 Value ($/ha)	1986 Yield (kg/ha)	1986 Disease index	1988 Value ($/ha)	1988 Yield (kg/ha)	1988 Disease index
McNair 944	10,079 NS[z]	2,639 NS	10.1**	3,590**	1,003**	48.3**	NT	NT	NT
K 399	11,134	2,887	2.1	8,332	2,293	13.2	10,425 NS	2,784 NS	3.3**
K 326	NT	NT	NT	NT	NT	NT	10,870	2,884	12.6
CV (%)	10.1	10.6	48.2	13.7	15.1	21.7	10.7	10.2	47.6
R^2	0.72	0.68	0.87	0.97	0.97	0.97	0.85	0.86	0.89

[x] Data for 1984 and 1986 are means of four crop sequences and four replications, and data for 1988 are means of four crop sequences, 1,3-dichloropropene + chloropicrin treatment and no treatment, and four replications. Disease index is calculated as $DI = \Sigma_{i=1}^{n} X_i [100 - (i-1)(100/n)]/I$, where i = ordinal evaluation number, X = number of diseased plants since previous count, n = number of evaluations, and I = initial number of plants in the plot.

[y] Disease resistance ratings: McNair 944 low, K 399 high, K 326 moderate.

[z] NS = means within a column do not differ significantly ($P = 0.05$) according to the F test. Means within a column differ significantly at ** = $P = 0.01$ and * = $P = 0.05$. NT = not tested.

red clover mixed with grasses, disease (4.9%) and crop vigor were only slightly greater than for tobacco after 5 yr of corn (3.7%), whereas tobacco in continuous tobacco plots was heavily diseased (81.3%). Smith (15) reported that the tobacco crop following 3 yr of native weeds had more than twice the disease (84%) of tobacco following 3 yr of corn (41%) and that soybean was one of the best rotation crops in long rotations. In a 2-yr rotation, soybeans reduced disease by over 50% (15), which agrees with our findings. Although rotation with a weed fallow has been considered superior to most other crops for yield conservation in fields infested with *P. solanacearum* (10), our results show soybeans to be equal or superior to a fescue/weed fallow in a 2-yr rotation. Others (8,15) have found weed fallows to be inferior to other rotation crops. These differences may be due to the weed species present and their host suitabilities for *P. solanacearum*.

The yearly variation in disease severity noted in our study was probably caused by differing temperature and moisture patterns. Possible weed-host populations were very low in tobacco, soybeans, and corn, and their role as pathogen food sources has been discounted by others in North Carolina (14–16). Weeds were believed to promote the survival of *P. solanacearum* (race 1) in rotation studies in the lowland tropics of Costa Rica (8). Ragweed did occur in our tests and was most prominent in the fescue rotation. Ragweed is a host for *P. solanacearum* (5) and, therefore, may have reduced the effectiveness of fescue as a rotational crop. Changing cultivars during 1987–1988 also affected results. Although K 326 had a higher disease index and is much more susceptible to bacterial wilt than is K 399, its total yield and leaf quality were great enough to compensate when disease severities were moderate.

Of the two factors, yield and quality, that contribute to value, increased yield accounted for all of the value increase. Yield was most highly correlated ($r = -0.95$) with disease index in 1986, probably because of the very high disease incidence that year. Correlations were moderate ($r = -0.67$) in 1984 and poor ($r = -0.32$) in 1988. Quality was unaffected except in 1988, when it was lower where tobacco followed soybeans. Lower quality of tobacco following soybeans has been attributed to excess nitrogen produced by soybean, and hence soybean is not a recommended rotation crop (7). Many producers avoid that crop sequence, although we believe a soybean-tobacco rotation in fields infested with *P. solanacearum* would be profitable. No fertilizer compensation was made in our study for excess nitrogen in tobacco following soybeans.

Fumigation with either 1,3-dichloropropene + chloropicrin or chloropicrin alone for control of bacterial wilt in North Carolina is a recommended practice and has been shown to be effective (13). In 1988, crop value and yield were higher as expected in the treated plots but not as an apparent result of reduced disease incidence or disease index. No explanation is offered for why fumigation was not effective for disease control in this study. However, apparent failure of fumigants in commercial production fields is not uncommon, especially where susceptible cultivars are grown continuously. No other diseases, except tobacco mosaic virus, were evident in the field.

Continued work is needed on the integration of economical crop sequences into a complete bacterial wilt management system. However, soybean, which traditionally has not been considered a good rotational crop with tobacco, is an excellent nonhost crop where bacterial wilt occurs, offsetting any potential negative agronomic effects.

ACKNOWLEDGMENTS

We thank David Porter, Keith Wood, and Pat Wickham for technical assistance, Larry Nelson for statistical assistance, and Kelvin Bass and Frankie Howell for their input and cooperation. This research was supported by the North Carolina Agricultural Research Service and by a grant from the North Carolina Tobacco Foundation, Inc.

LITERATURE CITED

1. Buddenhagen, I., and Kelman, A. 1964. Biological and physiological aspects of bacterial wilt caused by *Pseudomonas solanacearum*. Annu. Rev. Phytopathol. 2:203-230.
2. Csinos, A. S., Fortnum, B. A., Gayed, S. K., Reilly, J. J., and Shew, H. D. 1986. Evaluating chemicals for control of soilborne pathogens on tobacco. Pages 231-236 in: Methods for Evaluating Pesticides for Control of Plant Pathogens. K. D. Hickey, ed. American Phytopathological Society, St. Paul, MN.
3. Engelbrecht, M. C., and Prinsloo, G. C. 1985. *Pseudomonas solanacearum* on tobacco in South Africa. Phytophylactica 17:171-172.
4. Garner, W. W., Wolf, F. A., and Moss, E. C. 1917. The control of tobacco wilt in the flue-cured district. Bull. U.S. Bur. Plant Ind. 562.
5. Grand, L. F., ed. 1985. North Carolina Plant Disease Index. Page 12 in: N.C. Agric. Ext. Serv. Tech. Bull. 240 (rev.).
6. Grybauskas, A. P. 1989. Tobacco disease loss estimates 1988. Tob. Dis. Loss Eval. Comm. Rep. 37 pp.
7. Hawks, S. N., Jr., and Collins, W. K., eds. 1983. Principles of Flue-Cured Tobacco Production. Published by Hawks and Collins, Raleigh, NC. 358 pp.
8. Jackson, M. T., and Gonzalez, L. C. 1981. Persistence of *Pseudomonas solanacearum* (race 1) in naturally infested soil in Costa Rica. Phytopathology 71:690-693.
9. Kelman, A. 1953. The bacterial wilt caused by *Pseudomonas solanacearum*. N.C. Agric. Exp. Stn. Tech. Bull. 99. 194 pp.
10. Kincaid, R. R. 1960. Crop rotation and fallowing in relation to tobacco disease control. Bot. Rev. 26:261-276.
11. Lucas, G. B. 1975. Diseases of Tobacco. Biological Consulting Associates, Raleigh, NC. 621 pp.
12. Melton, T. A., Porter, D., and Wood, B. K. 1988. Disease control practices. Pages 62-95 in: Tobacco Information 1989. N.C. Agric. Ext. Serv. AG-187 (rev.).
13. Melton, T. A., Porter, D., and Wood, B. K. 1988. Extension-research flue-cured tobacco disease report 1988. N.C. Agric. Ext. Serv. AG-191. 114 pp.
14. Sequeira, L. 1962. Control of bacterial wilt of bananas by crop rotation and fallowing. Trop. Agric. 39:211-217.
15. Smith, T. E. 1944. Control of bacterial wilt of tobacco as influenced by crop rotation and chemical treatment of the soil. Circ. U.S. Dep. Agric. 692.
16. Smith, T. E., and Godfrey, R. K. 1939. Field survey of the relation of susceptible weed to Granville wilt control. (Abstr.) Phytopathology 29:22.