grown in the winter, no time is lost in the breeding cycle.

Mass inoculation and screening of young 6- to 8-week-old seedlings in a controlled environment is an effective means of incorporating red stele resistance into breeding material. The methods outlined above are simple procedures that can be readily adapted to the needs of most strawberry breeding programs.

Literature Cited

1. Draper, A. D., D. H. Scott, and J. L. Maas. 1970. Inoculation of strawberry with *Phytophthora fragariae*. *Plant Dis. Rptr.* 54:739-740.
2. Hickman, C. J. 1940. The red core root disease of the strawberry caused by *Phytophthora fragariae*, n. sp. *J. Pomol.* 18:89-118.
3. ———— and Mary P. English. 1951. Factors influencing the development of red core in strawberries. *Trans. British Mycol. Soc.* 34:223-236.
4. Jeffers, W. F. 1953. Cause and control of the red stele disease of strawberries. *Md. Agr. Expt. Sta. Bul.* 445.
5. Maas, J. L. 1970. Relation of the concentration of macerated mycelium of *Phytophthora fragariae* for infection of strawberry roots. *Plant Dis. Rptr.* 54:667-668.
6. Mussell, Harry and Florence E. Fay. 1971. A method for screening strawberry seedlings for resistance to *Phytophthora fragariae*. *Plant Dis. Rptr.* 55:471-472.
7. Scott, D. H., J. L. Maas, and A. D. Draper. 1975. Screening strawberries for resistance to *Phytophthora fragariae* with single versus a composite of races of the fungus. *Plant Dis. Rptr.* 59:207-209.
8. Waldo, G. F., G. M. Darrow, W. F. Jeffers, J. B. Damaree, and E. M. Meader. 1946. Breeding strawberries for resistance to red stele root disease. *Trnas. Peninsula Hort Soc.* 36:22-33.
9. Wynn, Willard K. 1968. Development of controlled conditions for the study of red stele disease of strawberries. *Contrib. Boyce Thompson Inst.* 24(4):95-102.

HortScience 11(3):258–260. 1976.

Red Stele Disease of Strawberry: Soil pH, Pathogen, and Cultivar Interactions[1]

John L. Maas[2]
Fruit Laboratory, Plant Genetics and Germplasm Institute, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, MD 20705

Additional index words. Fragaria X *ananassa, Phytophthora fragariae* races

Abstract. **The interrelationships among red stele infection (*Phytophthora fragariae* Hickman races A-2 and A-5), symptom development (in susceptible 'Blakemore' strawberry (*Fragaria* x *ananassa* Duch.) runner plants and 'Midland' x 'Midland' and 'Sequoia' x 'Earlibelle' seedlings), and soil pH were examined in two experiments. Percent of plants infected and disease symptom severity ratings were high when plants were grown in soil infested with *P. fragariae* race A-2 and soil pH 5.4 to 8.0. The length of incubation period had a greater effect on infection and disease development by race A-2 than did either soil pH or type of plant (runner plant or seedling). Symptom severity ratings among 'Blakemore' runner plants and 'Sequoia' x 'Earlibelle' seedlings grown in soil infested with race A-5 was highest at low to intermediate pH levels and decreased as soil pH increased. No direct relationship between soil pH and plant infection was found. Interactions among soil pH, pathogen race, and runner plant or seedling populations were significant.**

In recent years, 25–30,000 strawberry seedlings and cultivars have been screened annually against several races of the red stele causal fungus at the Beltsville Agricultural Research Center. Methods have been developed to efficiently and accurately screen large numbers of plants (2, 4, 5). Variation in screening results may occur and plants of advanced selections that passed the initial screening test when retested as mature runner plants occasionally proved to be susceptible to the pathogen. These plants may have accidently escaped infection in the initial test, or they may possess resistance in the juvenile stage.

The objective of this work was to investigate the susceptibility reactions of strawberry seedlings and runner plants to red stele. Since soil pH has also been shown to affect the development of red stele in strawberry plantings (3), the effect of soil pH was included as a variable.

An acid (pH 4.1–4.5) sandy-loam soil was coarse-screened (0.5 cm mesh) and amended with agricultural grade hydrated lime (CaO, 62%; MgO, 3%). Soil reaction treatments were established using the following lime rates, 0, 0.37, 0.74, 1.11, 1.48, 1.85, 2.22, 2.59, 2.96, 3.33, and 3.70 g/kg soil. Four replications were employed per treatment. Amended soil was placed in 15-cm-deep wooden boxes (31 kg soil per box) lined with 4 mil polyethylene sheeting folded and fastened on the outside to enable water to drain from boxes or be retained. Unplanted soil boxes were watered regularly in a greenhouse for 3.5 months. The soil was remixed prior to planting. Soil reaction of duplicate samples was measured in 1:1 suspensions of 1N KCl at the beginning and termination of the experiments. All measurements were made on samples in equilibrium with atmospheric CO_2 at 25°C with a Fisher Company Acumet 210 pH meter with glass electrodes.

Inoculum consisted of finely chopped roots of 'Blakemore' plants that were severely infected with *P. fragariae* race A-2. Roots of 5 or 6 plants per box were thoroughly mixed into soil prior to planting. One-half of each box was planted with 15 'Blakemore' runner plants, and the other half with 24 'Midland' self seedlings (designated as Group-1) in early Dec. Both populations were very susceptible to red stele disease. Seeds were germinated in milled sphagnum in flats in late September. Greenhouse temperature was maintained at 10–15°C. Supplemental incandescent lighting was provided to maintain a 16-hr photoperiod. Boxes were initially flooded for 4 days and then allowed to drain normally with daily watering.

Seedlings (Group-1) were examined for symptoms of red stele disease after 30 days. The rating system was based on a probability scale from 0–9 as a measure of plant symptom expression. It is a reversal of the scale used by others (1, 2, 5) which was instituted as a measure of plant health. A new planting of seedlings of 'Midland' self (designated as Group-2) of the same age as those removed, but 30 days older at transplanting time, were transplanted into the vacant half of each soil box, 24 plants per box. The Group 2 seedlings were examined 75 days after they were planted and the 'Blakemore' plants 90 days after planting. Percent of plants infected per group, and severity of symptoms on each plant were determined. In a similar experiment the following year, acid soil (pH 4.1) was amended with 0, 1.0, 2.2, 5, and 8.0 g lime/kg soil. Adjusted pH of the soil ranged from 4.1 to 7.9. Inoculum consisted of finely chopped roots of 7 'Blakemore' plants severely infected with *P. fragariae* race A-2 or A-5 mixed into each box of soil. Ten 'Blakemore' plants and 15 'Sequoia' x 'Earlibelle' seedlings (both parents very susceptible to red stele) were planted in separate halves of each box. Seedlings were planted on Dec. 20 and 'Blakemore' on Jan. 4. Boxes were flooded 4 days and allowed to drain with daily watering. Plants were examined for red stele symptoms on April

[1]Received for publication January 2, 1976. Mention of a trademark name or a proprietary product does not constitute a guarantee or warranty of the product by the USDA, and does not imply its approval to the exclusion of other products that may also be suitable.
[2]Research Plant Pathologist.

Table 1. Strawberry plants infected by *Phytophthora fragariae* race A-2 at several soil pH levels.

Soil pH	Infection (%)		
		Midland self seedlings[z]	
	Blakemore	Group 1	Group 2
4.4	77	61	31
5.4	100	79	66
5.7	100	85	72
6.3	100	83	72
6.7	100	96	70
6.8	100	88	70
7.2	100	90	56
7.6	100	90	85
7.7	100	89	54
7.8	100	83	78
8.0	100	92	57

[z]Midland self seedlings, Group-1, planted into soil immediately after inoculum was mixed into soil and removed after 30 days. Group-2 seedlings, planted into soil vacated by Group-1 seedlings, were removed after 75 days. Groups 1 and 2 were from the same seedling population.

Table 2. Severity of symptom expression in 'Blakemore' strawberry plants and 'Midland' self seedlings Groups 1 and 2 inoculated with *Phytophthora fragariae* race A-2 in soil amended with lime to various pH values.

Soil pH	Symptom severity[y]			
	Blakemore plants	Midland self seedlings		Mean
		Group-1	Group-2	
4.5	3.95	4.63	0.75	3.11a[z]
5.4	7.92	6.15	3.47	5.85b
5.7	7.83	6.82	4.10	6.25b
6.3	7.95	6.27	4.07	6.10b
6.7	7.48	6.20	3.05	5.57b
6.8	7.65	6.87	3.57	6.03b
7.2	6.97	6.75	2.67	5.37b
7.6	7.87	5.80	4.27	5.98b
7.7	7.35	6.17	2.80	5.44b
7.8	7.80	5.62	4.27	5.90b
8.0	7.37	7.15	2.15	5.55b
Plant means	7.28c	6.19b	3.20a	5.56

[z]Means separation by Duncan's multiple range test, 5% level.

[y]'Blakemore' plants were examined after 90 days. Rating system used: 0 = plants symptomless; 1 = a few root tips dead, but no red steles or oospores; 2 = a few root tips dead, red steles and oospores present; 3, 4, 5, 6, 7 = steles infected for a maximum of 10, 25, 50, 75, and 85% of the root length, respectively; 8 = some steles infected to the crown; 9 = most roots dead.

10. Soil pH determinations were made as previously indicated. Greenhouse was maintained at 10–15°C.

Fewer plants showed disease symptoms at pH 4.4 than at pH 5.4 or higher (Table 1). Similarly, symptom severity ratings were lower at pH 4.4 and increased to maximum ratings at pH 5.4–6.3 (Table 2). Symptom severity in Group 2 seedlings was significantly less than Group 1 seedlings and 'Blakemore' plants, respectively. No interaction between pH and plant group means was found, suggesting that each group reacted similarly to soil pH.

In the second experiment, all plants became infected, and severity of infection in 'Sequoia' x 'Earlibelle' seedlings by race A-2 was consistently high over the entire pH range (Table 3). 'Sequoia' x 'Earlibelle' seedlings infected with A-5 showed more intense symptom severity at pH 5.9 than at pH 7.1, and a sharp decrease in symptom severity as pH approached 8.0. 'Blakemore' plants infected with A-5 showed greatest symptom severity at pH 5.9 that gradually decreased with increased soil pH. Symptom ratings between A-2 and A-5, runner plant and seedling, and pH were significant. All interactions were significant.

In the first experiment, 'Midland' self (Group-2) seedlings and 'Blakemore' plants, although genotypically different but both susceptible to race A-2, developed the most severe symptoms at soil pH 5.7–6.3. This was true in the second experiment with 'Blakemore' plants and 'Sequoia' x 'Earlibelle' seedlings infected with race A-2. In the first experiment, 'Blakemore' plants were grown in infested soil for 90 days, seedling Group-1 for 30 days, and seedling Group-2 for 75 days. In the second experiment, 'Blakemore' was grown for 125 days and 'Sequoia' x 'Earlibelle' seedlings for 140 days. Under these circumstances, disease severity may gradually level off to a uniformly high level over this range of soil pH as the period of incubation is extended. Group-2 'Midland' self seedlings may be exceptions because a definite maximum severity level was apparent at pH 5.7, and a decline in severity was evident as pH increased. Although this group of seedlings was grown for 75 days (compared to 30 days for Group-1) in infested soil, the potential of inoculum to cause disease may have atrophied. Similar loss of infectivity in soil after successive seedling plantings has also been noted in our screening program (D. H. Scott, personal communication). Hickman and English (3) in short-term (3 weeks) greenhouse experiments with *P. fragariae* showed reduced disease severity in 'Huxley' plants at high soil pH (pH 8.0–8.5) than at intermediate levels (pH 6–7.5). Unfortunately, they did not continue their experiments long enough to observe if a gradual increase in symptom severity occurred with time at high pH levels, and they used only one unidentified isolate of the pathogen and one susceptible cultivar.

'Blakemore' and 'Sequoia' x 'Earlibelle' seedling plants inoculated with race A-5 exhibited different disease severity and soil pH interactions than plants inoculated with race A-2. The most severe disease symptoms attributed to race A-5 were at pH 5.9, declining sharply at pH values approaching 7.8 to 8.0. Apparently, soil pH above pH 7.1 limited symptom severity after at

Table 3. Severity of symptom expression in 'Blakemore' plants, after 125 days, and 'Sequoia' x 'Earlibelle' seedlings, after 140 days, inoculated with *Phytophthora fragariae* races A-2 and A-5.

Soil pH	Symptom severity[y]												
	Blakemore plants				Sequoia x Earlibelle				Difference (Plant mean)	pH mean	Race mean		Difference (Race mean)
	Race A-2	Race A-5	Difference (races)	Plant mean	Race A-2	Race A-5	Difference (races)	Plant mean			A-2	A-5	
4.1	6.60ab[z]	3.35b	3.25ab	4.98ab	6.98a	5.75b	1.23b	6.36b	1.38	5.67ab	6.79a	4.55b	2.24
5.9	7.38b	4.32c	3.06a	5.85b	7.25a	7.85c	0.65b	7.55c	1.70	6.70c	7.31a	6.09b	1.22
7.1	5.88a	2.83ab	3.05a	4.35a	7.65a	6.00b	0.65b	6.83bc	2.48	5.59ab	6.76a	4.41b	2.35
7.8	6.88ab	2.25a	4.63ab	4.56a	7.40a	6.28bc	1.12b	6.84bc	2.28	5.70ab	7.14a	4.26b	2.88
7.9	7.28b	2.45a	4.83b	4.86a	7.43a	2.80a	4.63a	5.11a	0.25	4.99a	7.35a	2.36a	4.99
Mean	6.80c	3.04a		4.92a	7.34c	5.74b		6.54b		5.73	7.07b	4.39a	

[z]Means separation in columns and means among comparable interaction by Duncan's multiple range test, 5% level.

[y]Rating system used: 0 = plants symptomless; 1 = a few root tips dead, but no red steles or oospores; 2 = a few root tips dead, red steles and oospores present; 3, 4, 5, 6, 7 = steles infected for a maximum of 10, 25, 50, 75, and 85% of the root length, respectively; 8 = some steles infected to the crown; 9 = most roots dead.

least 125 days, even though infection occurred in 100% of the plants.

Races of the pathogen and susceptible host genotypes may interact differently under different soil conditions. Hickman and English (3) found that soil type affected their results greatly. Some alkaline soils were conducive to *P. fragariae* infection and disease development and others were not. They concluded, as was found here, that there was not a direct relationship between soil pH and red stele disease development. Consequently, the consideration that cultivars normally susceptible to *P. fragariae* can persist in infested soil but show minimal disease symptoms may be valid as was observed with *P. fragariae* race A-5. Under these conditions susceptible plants might be mistakenly rated as highly resistant to the disease in a screening test. In the field the pathogen could conceivably be transferred from one field location to another in propagation material that appears to be disease free.

Literature Cited

1. Converse, R. H. and D. H. Scott. 1962. Physiologic specialization in *Phytophthora fragariae*. *Phytopathology* 52:802-807.
2. Draper, A. D., D. H. Scott, and J. L. Maas. 1970. Inoculation of strawberry with Phytophthora fragariae. *Plant Dis. Rptr.* 54:739-740.
3. Hickman, C. J. and M. P. English. 1951. Factors influencing the development of red core in strawberries. *Trans. Brit. Myc. Soc.* 34:223-236.
4. Maas, J. L. 1970. Relation of concentration of macerated mycelium of Phytophthora fragariae for infection of strawberry roots. *Plant Dis. Rptr.* 54:667-668.
5. Scott, D. H., J. L. Maas, and A. D. Draper. 1975. Screening strawberries for resistance to Phytophthora fragariae with single versus a composite of races of the fungus. *Plant Dis. Rptr.* 59:207-209.

HortScience 11(3):260–261. 1976.

Observations on Vegetative and Reproductive Growth in Blueberry[1]

R. E. Gough, V. G. Shutak, and N. D. Windus
Department of Plant and Soil Science, University of Rhode Island, Kingston, RI 02881

Additional index words. Vaccinium corymbosum, wood thickness, flower buds, vegetative buds, growth flushes, bud location

Abstract. **Earlier ripening cultivars of blueberry (*Vaccinium corymbosum* L.) usually produced more vegetative growth flushes than later ripening cultivars. Multiple flower buds were found most frequently on thick wood regardless of cultivar. Most distal buds on any flush were flower buds, while proximal buds were usually vegetative.**

The growth and fruiting habits of the cultivated highbush blueberry have been reported by several researchers. These include the frequent occurrence of 2 flushes of vegetative growth in 1 season (3, 6, 8) and the formation of single, axillary flower buds on the distal portion and vegetative buds on the proximal portion of the new growth (1–6). Shutak (8) reported the formation of double flower buds on 'Coville' bushes sprayed with 5000 ppm succinic acid-2,2-dimethylhydrazide (SADH). Observations on the no. of flushes, the order of flower and vegetative bud succession along the shoot, and the frequency of occurrence of multiple flower buds are reported below.

Observations were conducted during March, 1975, on bushes of 'Earliblue', 'Herbert', 'Bluecrop', 'Coville', 'Bluetta', and 'Lateblue' growing under a sawdust mulch on Narragansett loam soil. All bushes received 1 kg of 5N-4.3P-8.3K fertilizer annually. Shoots were separated into 3 thickness classes as previously described by Hindle et al. (7). Ten medium-thick shoots per bush on each of 5 bushes of each cultivar were observed in relating the no. of flushes to cultivar. Five shoots of each thickness per bush on each of 5 bushes of each cultivar were used in relating the occurrence of multiple flower buds to shoot thickness and in determining bud type locations. Any bud that did not have the typical spheroidal shape of flower bud was considered a vegetative bud. Data for relating growth flushes to cultivar are expressed as total no. of flushes occurring on 10 shoots per bush per cultivar.

[1]Received for publication July 12, 1975. Contribution No. 1617, Rhode Island Agricultural Experiment Station, Kingston, RI.

Table 2. Occurrence of multiple flower buds (25 shoots per cultivar).

Cultivar	No. of multiple flower buds: Thin wood	Medium wood	Thick wood	Means[z]
Earliblue	0	5	48	17.7 a
Bluecrop	0	3	13	5.3 a
Coville	2	1	33	12.0 a
Means	.7 a	3.0 a	31.0 b	

[z]Mean separation within rows or columns by Duncan's multiple range test, 5% level.

In most cases, the later the season of fruit ripening, the lower the incidence of multiple flushes (Table 1). This relationship appeared to breakdown somewhat, however, in the case of 'Lateblue', which behaved similar to a midseason rather than a lateseason cultivar.

Flower buds were interspersed with vegetative buds on all flushes and not merely on the distal portion of the new shoot. Though most buds were single, the appearance of multiple flower buds was not uncommon and was found

Table 1. Relationships of growth flushes on medium thick wood to 6 blueberry cultivars.

Bush	No. growth flushes per 10 shoots: Bluetta[z]	Earliblue	Bluecrop	Herbert	Coville	Lateblue
1	17	14	13	15	10	14
2	20	15	16	13	11	15
3	19	21	18	17	10	11
4	19	22	15	16	10	17
5	19	13	14	12	10	20
Mean	19.6 a[y]	17.0 ab	15.2 b	14.6 b	10.2 c	15.4 b

[z]Cultivars listed in order of fruit ripening, early to late.
[y]Mean separation by Duncan's multiple range test, 5% level.

Table 3. Relationship of growth flush to distal and proximal bud type.

Wood type	Location	Earliblue: No. flower buds	Earliblue: No. vegetative buds	Bluecrop: No. flower buds	Bluecrop: No. vegetative buds
Thin	End flush 1	22.00	3.00	22.00	3.00
	Begin flush 2	1.00	24.00	1.00	24.00
Medium	End flush 1	22.00	3.00	25.00	0.00
	Begin flush 2	0.00	25.00	0.00	25.00
Thick	End flush 1	4.00	21.00	7.00	18.00
	Begin flush 2	0.00	25.00	3.00	22.00

[z]Data taken on 25 shoots of each shoot thickness.