EVALUATION OF RELATIVE RESISTANCE OF DIFFERENT STRAWBERRY CULTIVARS TO *PHYTOPHTHORA* AND *VERTICILLIUM DAHLIAE* AS A POTENTIAL ALTERNATIVE TO METHYL BROMIDE

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Strawberries in California's commercial fields are subject to decline and death caused by soil-borne pathogens such as: *Verticillium dahliae*, *Colletotrichum acutatum* and several *Phytophthora* spp. (*P. cactorum*, *P. citricola*, *P. fragariae*, *P. parasitica*) and an unidentified *Phytophthora* sp. (designated as isolate SB890). Our studies showed that *P. cactorum* is the most frequently isolated *Phytophthora* sp. from strawberry and that *P. citricola* and *Phytophthora* sp. SB890 are usually recovered from fields with a high incidence of dead plants. *P. fragariae* has been occasionally isolated from collapsed plants during cool wet weather. Pathogenicity tests in artificially infested soil also revealed that *P. citricola* and *Phytophthora* sp. SB890 are more virulent in strawberry than either *P. parasitica* or *P. cactorum*.

Methyl bromide:chloropicrin mixture as a preplant soil fumigant effectively controls several soil-borne pests and pathogens, including *Phytophthora* and *Verticillium* species. These fungi can greatly affect profitability of strawberry production in California. We have investigated the feasibility of using genetic resistance to *Phytophthora* spp. and *Verticillium* sp. in strawberries as an alternative to methyl bromide fumigation. The approach, particularly if combined with careful soil water management, could be both economically effective and environmentally desirable, and could serve as one component of an integrated strategy for control of Verticillium wilt and Phytophthora root and crown rot of strawberry.

Our previous research on the relative resistance of 12 strawberry cultivars (Capitola, Chandler, Commander, Douglas, Fern, Irvine, Muir, Pajaro, Parker, Sheehy, Tioga and Yolo) to *P. cactorum* and *P. citricola* in artificially infested soil under greenhouse conditions revealed marked differences in resistance to these pathogens among the twelve strawberry cultivars.

During the 1995-96 growing season we studied comparative growth and yield of nine different strawberry cultivars (Anaheim, Camarosa, Capitola, Chandler, Douglas, Irvine, Laguna, Seascape and Selva) in the field. Treatments were as follows: one section naturally infested with *Verticillium dahliae* and experimentally infested with field soil containing *P. cactorum*, *P. citricola* and *Phytophthora* sp. SB890 was preplant fumigated in August 1994 and 1995 (EI94F9495) with a methyl bromide:chloropicrin mixture (57:43%) at the rate of 375 lbs/acre by the flat bed fumigation method and covered immediately with sealed polyethylene tarps; one section containing the same pathogens was preplant fumigated in the same manner in August 1993 but not fumigated for the 1994-1995 or 1995-1996 growing seasons (EI93F93NF9495); one section containing the same pathogens was nonfumigated in the 1993-1994, 1994-1995 and 1995-1996 strawberry growing seasons (EI93NF939495); one section never previously cropped to strawberry and naturally infested with *Verticillium dahliae* was not preplant fumigated during the 1995-1996 growing season (NEINF95). Fifty-two inch planting beds were prepared with drip irrigation lines and covered with black over black polyethylene mulch. Strawberry plants were planted 16 inches apart in two rows on each bed, either on September 11 or September 20 (summer planting) or on October 20 or November 11 (winter planting) depending on cultivar. Some cultivars were both summer and winter planted. Each cultivar was represented in 5 replicated plots, whereas each replicate plot consisted of 10 plants per cultivar. The replicate plots were randomized within blocks within the sections. The effects of methyl bromide:chloropicrin soil fumigation as well as relative resistance of individual strawberry cultivars was based on the disease severity rating (DSR) and cumulative total (marketable + nonmarketable) yield (trays/acre) collected by weekly harvest from March 26 through August 13, 1996. DSR was based on the above ground symptoms in strawberry plants where: 0 = good vigorous growth; 1 = slightly stunted

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growth; 2 = visible stunted growth; 3 = pronounced stunted growth with few fruits; 4 = nearly dead plant, and 5 = dead plant. Isolations of *Phytophthora* spp. and *Verticillium dahliae* were attempted from collapsed or dead plants. Soil from each fumigation treatment was assayed for *Phytophthora* spp. and *Verticillium dahliae* at season end.

Phytophthora spp. and *Verticillium* dahliae were consistently recovered from symptomatic plants throughout the 1995-1996 growing season. In addition, we assayed soil from replications of selected treatments for the inoculum density of *Verticillium dahliae* in August 1996.

The results on vigor and yield of six summer planted strawberry cultivars (Capitola, Chandler, Douglas, Irvine, Seascape and Selva) under the different fumigation treatments are summarized in Fig. 1, Table 1 and Table 2. The results on vigor and yield of six winter planted strawberry cultivars (Anaheim, Camarosa, Capitola, Chandler, Laguna and Selva) under the different fumigation treatments are summarized in Fig. 2, Table 3 and Table 4.

Among summer planted cultivars in *Phytophthora* spp. and *Verticillium* sp. infested, nonfumigated soil (EI93NF939495) the percent of plants with a DSR≥3 ranged from 16% for Selva to 70% for Capitola (Fig. 1), whereas yield for the same cultivars ranged from 3,734 trays/acre for Selva to 2,186 trays/acre for Capitola (Table 1). In soil containing the same pathogens and preplant fumigated in 1994 and 1995 (EI94F9495), the percent of plants with a DSR≥3 ranged from 0% for Capitola to 4% for Chandler (Fig. 1), with yield ranging from 4,870 trays/acre for Chandler to 9,166 trays/acre for Capitola (Table 1). In soil containing the same pathogens and preplant fumigated in 1993 but not 1994 and 1995 (EI93F93NF9495), the percent of plants with a DSR≥3 ranged from 2% for Chandler to 41% for Irvine (Fig. 1), with yield ranging from 3,242 trays/acre for Irvine to 5,50347 trays/acre for Capitola (Table 1).

In soil that was naturally infested with indigenous *Verticillium dahliae* only and nonfumigated, the percent of plants with a DSR≥3 ranged from 65% for Chandler to 96% for Capitola (Fig. 1), while yield ranged from 1,310 trays/acre for Irvine to 3,065 trays/acre for Selva (Table 2).

The relative performance of the summer and winter planted Capitola within fumigation treatments was similar (Table 1 and 2). However it appears that Chandler and Selva performed better when summer rather than winter planted in soil where *Phytophthora* spp. and a low level of *Verticillium dahliae* were present, and they performed similarly in the soil that had no *Phytophthora* and had a high level of *Verticillium dahliae* inoculum (Table 1 and 2).

Among winter only planted cultivars in nonfumigated soil infested with *Phytopthtora* spp. and *Verticillium* sp. (EI93NF939495), DSR≥3 was 44%, 54% and 92% for Anaheim, Laguna and Camarosa respectively (Fig. 2) whereas yield was 2,273, 2,056 and 1,803 trays/acre respectively (Table 3). In soil containing the same pathogens and preplant fumigated in 1994 and 1995 (EI94F9495), the percent of plants with a DSR≥3 was 2, 8, and 2, whereas yield was 3,950, 5,370 and 6,389 trays/acre for Anaheim, Laguna and Camarosa respectively. In soil containing the same pathogens and preplant fumigated in 1993 but nonfumigated in 1994 and 1995 (EI93F93NF9495), the percent of plants with a DSR≥3 was 24, 36, and 48, and yielded 2,313, 2,366, and 3,676 trays/acre for Anaheim, Laguna and Camarosa respectively. On the other hand, in soil that was naturally infested with indigenous *Verticllium* sp. only and nonfumigated the percent of plants with a DSR≥3 was 82, 92 and 100, and yield was 1,900, 1,132 and 1,009 trays/acre for Anaheim, Laguna and Camarosa respectively.

Among all cultivars growing in soil infested with indigenous *Verticillium dahliae* at an average of 27 propagules per gram of soil, there was less difference in yield and DSR≥3 than among the same cultivars grown in soil infested with *Phytophthora* spp. and *Verticillium dahliae* at an average of 14.6 propagules per gram of soil or less (Table 1, 2 3 and 4), suggesting that there are greater differences in resistance among the tested cultivars to *Phytophthora* spp. than to *Verticillium dahliae*. However, the level of resistance to either *Phytophthora* spp. or *Verticillium dahliae* in the tested cultivars may not be sufficient enough to equal the beneficial effect of methyl bromide:chloropicrin preplant soil fumigation for profitable commercial strawberry production in California.

Our research however showed that a preplant soil fumigation with methyl bromide:chloropicrin mixture (57:43%) at the rate of 375 lbs/acre is very effective in controlling several *Phytophthora* spp. and *Verticillium dahliae* in commercial strawberry fields, emphasizing the importance of preplant soil fumigation for profitable production of strawberry in California.

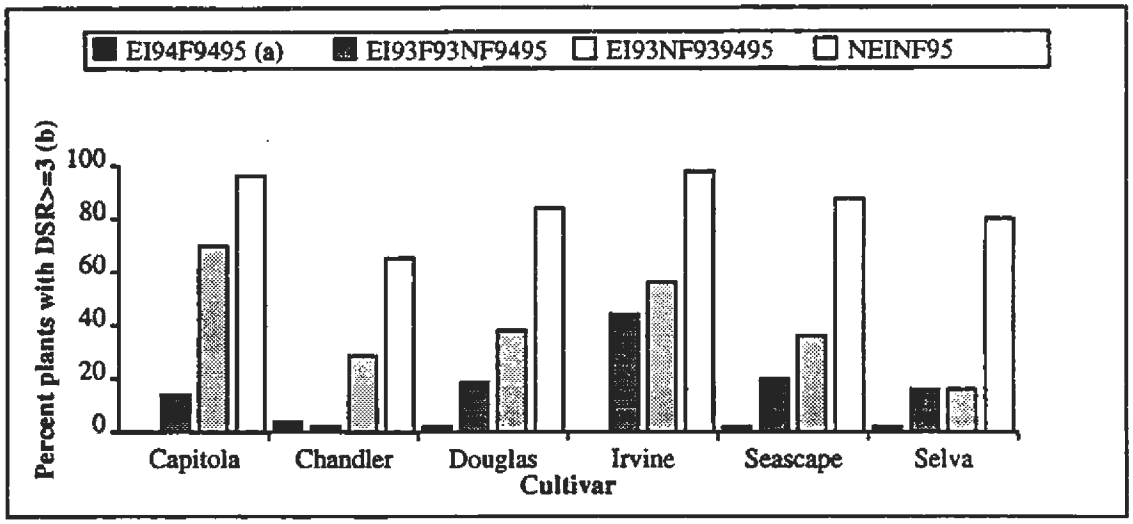

Figure 1. Effectiveness of preplant soil fumigation with methyl bromide:chloropicrin mixture (57:43%) 375 lbs/acre on disease severity rating (DSR) of six summer planted strawberry cultivars in soil experimentally infested with *Phytophthora cactorum*, *P. citricola*, *Phytophthora* spp. SB890, and naturally infested with *Verticillium dahliae*.

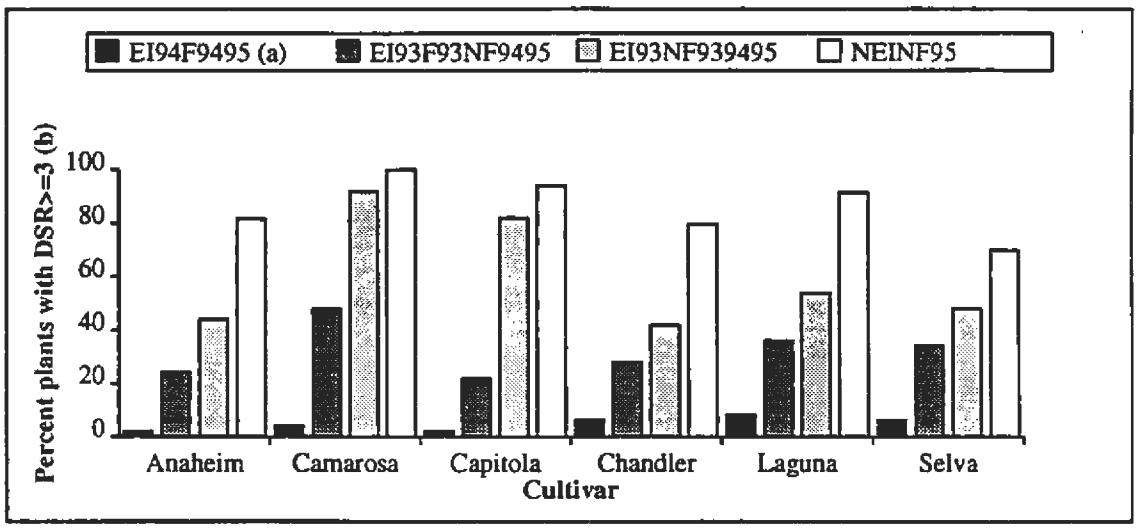

Figure 2. Effectiveness of preplant soil fumigation with methyl bromide:chloropicrin mixture (57:43%) 375 lbs/acre on disease severity rating (DSR) of six winter planted strawberry cultivars in soil experimentally infested with *Phytophthora cactorum*, *P. citricola*, *Phytophthora* spp. SB890, and naturally infested with *Verticillium dahliae*.

a Treatments for 1995-96 growing season:
EI94F9495 = Experimentally infested with *Phytophthora* spp. in 1994, fumigated in 1994 and 1995, and under strawberry 1994-95 and 1995-96 growing seasons. Average number of indigenous *Verticillium dahliae* propagules per gram of soil was 2.6 in August 1996.
EI93F93NF9495 = Experimentally infested with *Phytophthora* spp. in 1993, fumigated in 1993 and under strawberry 1993-94 growing season; nonfumigated and under strawberry 1994-95 and 1995-96 growing seasons. Average number of indigenous *Verticillium dahliae* propagules per gram of soil was 0.3 in August 1996
EI93NF939495 = Experimentally infested with *Phytophthora* spp. in 1993, nonfumigated and under strawberry 1993-94, 1994-95 and 1995-96 growing seasons. Average number of indigenous *Verticillium dahliae* propagules per gram of soil was 14.6 in August 1996.
NEINF95 = Nonexperimentally infested and nonfumigated and under strawberry 1995-96 growing season. Average number of indigenous *Verticillium dahliae* propagules per gram of soil was 27.0 in August 1996.

b DSR based on: 0 = symptomless, vigorous plant; 3 = pronounced stunted growth with few fruits; 5 = dead plant.

Table 1. Comparative yield of six different summer planted strawberry cultivars in soil experimentally infested with *Phytophthora cactorum*, *P. citricola*, *Phytophthora* spp. SB890, and naturally infested with *Verticillium dahliae* that was preplant fumigated with methyl bromide:chloropicrin (57:43%) mixture at the rate of 375 lbs/acre or nonfumigated in Watsonville, California.

	TREATMENTS							
	EI94F9495 (a)		EI93F93NF9495 (b)			EI93NF939495 (c)		
Cultivar	Yield (Trays/A)		Yield (Trays/A)		Percent yield loss (d)	Yield (Trays/A)		Percent yield loss (d)
Capitola	9,166 (e)	A (f)	5,503	A	40	2,186	C	76
Seascape	7,062	AB	4,617	ABC	35	3,190	AB	55
Douglas	6,818	B	3,535	BC	48	2,836	BC	58
Irvine	6,163	B	3,242	C	47	2,111	C	66
Selva	5,409	B	5,049	AB	7	3,734	A	31
Chandler	4,870	B	4,002	ABC	18	2,870	BC	41

a EI94F9495 = Experimentally infested with *Phytophthora* spp. in 1994, fumigated in 1994 and 1995, and under strawberry 1994-95 and 1995-96 growing seasons. Average number of indigenous *Verticillium dahliae* propagules per gram of soil was 2.6 in August 1996.

b EI93F93NF9495 = Experimentally infested with *Phytophthora* spp. in 1993, fumigated in 1993 and under strawberry 1993-94 growing season; nonfumigated and under strawberry 1994-95 and 1995-96 growing seasons. Average number of indigenous *Verticillium dahliae* propagules per gram of soil was 0.3 in August 1996.

c EI93NF939495 = Experimentally infested with *Phytophthora* spp. in 1993, nonfumigated and under strawberry 1993-94, 1994-95 and 1995-96 growing seasons. Average number of indigenous *Verticillium dahliae* propagules per gram of soil was 14.6 in August 1996.

d Percent yield loss expressed as percent of fumigated 1995 treatment (EI94F9495).

e Yield expressed as trays/acre of both marketable and nonmarketable fruit harvested weekly from 3/26/96 through 8/13/96.

f Figures with the same letter are not significantly different according to Duncan's mean separation at $\alpha = 0.01$

Table 2. Comparative yield of six different summer planted strawberry cultivars in soil experimentally infested with *Phytophthora cactorum*, *P. citricola*, *Phytophthora* spp. SB890, and naturally infested with *Verticillium dahliae* that was preplant fumigated with methyl bromide:chloropicrin (57:43%) mixture at the rate of 375 lbs/acre, or nonfumigated soil naturally infested only with *Verticillium dahliae* in Watsonville, California.

	TREATMENTS				
	EI94F9495 (a)		NEINF95 (b)		
Cultivar	Yield (Trays/A)		Yield (Trays/A)		Percent yield loss (c)
Capitola	9,166 (d)	A (e)	2,056	AB	78
Seascape	7,062	AB	2,046	AB	71
Douglas	6,818	B	2,504	AB	63
Irvine	6,163	B	1,310	B	79
Selva	5,409	B	3,065	A	43
Chandler	4,870	B	2,217	AB	54

a EI94F9495 = Experimentally infested with *Phytophthora* spp. in 1994, fumigated in 1994 and 1995, and under strawberry 1994-95 and 1995-96 growing seasons. Average number of *Verticillium dahliae* propagules per gram of soil was 2.6 in August 1996.

b NEINF9495 = Nonexperimentally infested and nonfumigated and under strawberry 1995-96 growing season. Average number of indigenous *Verticillium dahliae* propagules per gram of soil was 27.0 in August 1996.

c Percent yield loss expressed as percent of fumigated 1995 treatment (EI94F9495).

d Cumulative yield expressed as trays/acre of both marketable and nonmarketable fruit harvested weekly from 3/26/96 through 8/13/96.

e Figures with the same letter are not significantly different according to Duncan's mean separation at $\alpha = 0.01$

Table 3. Comparative yield of six different winter planted strawberry cultivars in soil experimentally infested with *Phytophthora cactorum*, *P. citricola*, *Phytophthora* spp. SB890, and naturally infested with *Verticillium dahliae* that was preplant fumigated with methyl bromide:chloropicrin (57:43%) mixture at the rate of 375 lbs/acre or nonfumigated in Watsonville, California.

	TREATMENTS							
	EI94F9495 (a)		EI93F93NF9495 (b)			EI93NF939495 (c)		
Cultivar	Yield (Trays/A)		Yield (Trays/A)		Percent yield loss (d)	Yield (Trays/A)		Percent yield loss (d)
Capitola	6,462 (e)	A (f)	4,038	A	38	1,894	A	71
Camarosa	6,389	A	3,676	AB	42	1,803	A	72
Chandler	6,061	A	2,568	AB	58	2,467	A	59
Selva	5,496	AB	2,805	B	49	2,274	A	59
Laguna	5,370	AB	2,366	B	56	2,056	A	62
Anaheim	3,950	B	2,313	B	41	2,273	A	42

a EI94F9495 = Experimentally infested with *Phytophthora* spp. in 1994, fumigated in 1994 and 1995, and under strawberry 1994-95 and 1995-96 growing seasons. Average number of indigenous *Verticillium dahliae* propagules per gram of soil was 2.6 in August 1996.

b EI93F93NF9495 = Experimentally infested with *Phytophthora* spp. in 1993, fumigated in 1993 and under strawberry 1993-94 growing season; nonfumigated and under strawberry 1994-95 and 1995-96 growing seasons. Average number of indigenous *Verticillium dahliae* propagules per gram of soil was 0.3 in August 1996.

c EI93NF939495 = Experimentally infested with *Phytophthora* spp. in 1993, nonfumigated and under strawberry 1993-94, 1994-95 and 1995-96 growing seasons. Average number of indigenous *Verticillium dahliae* propagules per gram of soil was 14.6 in August 1996.

d Percent yield loss expressed as percent of fumigated 1995 treatment (EI94F9495).

e Yield expressed as trays/acre of both marketable and nonmarketable fruit harvested weekly from 3/26/96 through 8/13/96.

f Figures with the same letter are not significantly different according to Duncan's mean separation at $\alpha = 0.01$

Table 4. Comparative yield of six different winter planted strawberry cultivars in soil experimentally infested with *Phytophthora cactorum*, *P. citricola*, *Phytophthora* spp. SB890, and naturally infested with *Verticillium dahliae* that was preplant fumigated with methyl bromide:chloropicrin (57:43%) mixture at the rate of 375 lbs/acre, or nonfumigated soil naturally infested only with *Verticillium dahliae* in Watsonville, California.

	TREATMENTS				
	EI94F9495 (a)		NEINF95 (b)		
Cultivar	Yield (Trays/A)		Yield (Trays/A)		Percent yield loss (c)
Capitola	6,462 (d)	A (e)	1,919	BC	70
Camarosa	6,389	A	1,009	C	84
Chandler	6,061	A	3,199	A	47
Selva	5,496	AB	2,676	AB	51
Laguna	5,370	AB	1,132	BC	79
Anaheim	3,950	BC	1,900	BC	52

a EI94F9495 = Experimentally infested with *Phytophthora* spp. in 1994, fumigated in 1994 and 1995, and under strawberry 1994-95 and 1995-96 growing seasons. Average number of *Verticillium dahliae* propagules per gram of soil was 2.6 in August 1996.

b NEINF95 = Nonexperimentally infested and nonfumigated and under strawberry 1995-96 growing season. Average number of indigenous *Verticillium dahliae* propagules per gram of soil was 27.0 in August 1996.

c Percent yield loss expressed as percent of fumigated 1995 treatment (EI94F9495).

d Cumulative yield expressed as trays/acre of both marketable and nonmarketable fruit harvested weekly from 3/26/96 through 8/13/96.

e Figures with the same letter are not significantly different according to Duncan's mean separation at $\alpha = 0.01$