Evaluation of Fumigation and Rhizomania-Tolerant Cultivars for Control of a Root Disease Complex of Sugar Beets

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ABSTRACT

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Field studies were conducted in 1991 and 1993 to evaluate the effectiveness of Telone II fumigation and rhizomania-tolerant cultivars to control a complex of soilborne pathogens (*Rhizoctonia solani, Aphanomyces cochlioides, Fusarium oxysporum* f. sp. *betae*, and beet necrotic yellow vein virus). Fifteen cultivars (13 rhizomania-tolerant and two rhizomania-susceptible) were included in a randomized complete block split-plot design with six replications in which main plots were fumigated or nonfumigated and cultivars were subplots. Data collected included root yield, gross sucrose, percent sucrose, disease index, and final stand. Although there were yield differences between repeated studies, similar trends were observed both years, including a significant fumigation × cultivar interaction. Yield of Tx18, HH67, and Maribo Record was consistently improved by fumigation, whereas yield of 88I139-03, Rhizosen, Maribo Turbo, and TxMH2 responded least to fumigation. Disease index, root yield, and gross sucrose were the variables most improved by fumigation, whereas percent sucrose and final stand were seldom affected. The rhizomania-tolerant cultivars, whether fumigated or not, did not yield as well as the locally adapted Tx18 check. Tx18 responded well to fumigation and even without fumigation yielded as well as or better than the rhizomania-tolerant (but not locally adapted) cultivars with fumigation. To our knowledge, this is the first report of a fumigation × cultivar interaction. Thus, fumigation can be beneficial to Texas sugar beet growers for control of multiple soilborne pathogens, depending on the cultivars planted.

Additional keywords: *Beta vulgaris*, fungal root rots, furoviruses, resistance

Approximately 17,000 ha of sugar beets are grown annually in Texas, concentrated primarily in a three-county area in the Panhandle where diseases are the major limitation to profitable production (24). Foliar diseases such as powdery mildew, Cercospora leaf spot, and curly top occur but can be controlled relatively effectively. Diseases caused by soilborne pathogens usually cause more devastating losses because they are difficult to detect before serious damage occurs, and control measures, if available, often are ineffective or impractical.

Over the last decade, the presence of a complex of root-rotting pathogens has been associated with significant yield reductions to Texas sugar beet growers. This soilborne complex consists of *Rhizoctonia solani* Kühn, *Aphanomyces cochlioides* Drechs., *Fusarium oxysporum* Schlechtend.:Fr. f. sp. *betae* (Stewart) Snyd. & Hans., and beet necrotic yellow vein virus (BNYVV) and, to a lesser extent, of *Pythium ultimum* Trow and *P. aphanidermatum* (Edson) Fitzp. The only nonfungal pathogen in this group, BNYVV, is transmitted and disseminated by the cosmopolitan fungus *Polymyxa betae* Keskin. Ordinarily, several of these pathogens are found simultaneously in the same field.

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In addition to root rot, *A. cochlioides, R. solani*, and *Pythium* spp. (24) cause seedling disease. The most commonly observed seedling disease, black root, is caused by *Aphanomyces* (24,25,27). Rhizoctonia seedling disease, caused by *R. solani* AG-4, is usually not a major problem in Texas but can be in other parts of the country (26,34,35). This disease is similar to black root in that it is most problematic in warm, wet soils. Unlike *Aphanomyces* or *Rhizoctonia, Pythium* sp. can initiate disease in cooler soils, where it attacks seeds and causes preemergence damping-off. *A. cochlioides* and *R. solani* normally cause postemergence damping-off (24).

Rhizoctonia root and crown rot, caused by *R. solani* AG-2-2, is the most prevalent of the fungal root rots in Texas (24,26). By the end of August, it can be identified in most fields but usually not at economically damaging levels. Leaves of infected beets wilt rapidly and seldom recover. Black lesions develop on the root and coalesce as disease progresses.

Although not as prevalent as Rhizoctonia root and crown rot, Aphanomyces root rot is usually economically damaging if present in fields. Symptoms of Aphanomyces root rot are easily distinguished from the black, primarily external lesions associated with Rhizoctonia root rot. *A. cochlioides* causes yellowish, water-soaked lesions that extend into the center of the root. As disease progresses, lesions become darker and finally turn jet black on the surface, with yellowish brown interior (17,24). These lesions can occur anywhere on the taproot but usually occur toward the distal end as a tip rot. Finally, the root tissue disintegrates, leaving only vascular strands intact.

Fusarium root rot is the least understood of the major diseases in Texas. It is similar to Fusarium yellows reported throughout the western United States in that symptoms include leaf yellowing, vascular necrosis, and wilting (16,24). In Texas, however, the disease is also characterized by a jet black rot at the distal end of the beet (16,24). As with Aphanomyces root rot, rotted cortical tissue disintegrates, leaving only the remnants of vascular elements. The tip rot symptom of Fusarium root rot is difficult to distinguish from that of Aphanomyces root rot, but vascular necrosis above the rotted portion is diagnostic for *Fusarium*.

BNYVV, which causes the disease rhizomania, was discovered in Texas and reported about the same time as *A. cochlioides* (3,21). Root symptoms include stunting and constriction of the taproot with vascular discoloration confined primarily to the central stele. Early infection by BNYVV also causes a proliferation of secondary rootlets (7,8,15,24), which is considered the most distinctive symptom.

Although not usually a serious problem for Texas growers, Pythium root rot, caused primarily by *P. aphanidermatum*, can be found sporadically in midsummer. Optimum disease development occurs at high soil temperatures (27–34 C) and moisture levels of 0 to −1 bar for 24–48 hr (29). Conditions such as these are uncommon in Texas, so damage due to Pythium root rot, even if it is present, is often minimal. Another *Pythium* species, *P. deliense* Meurs, has also been identified as a root rot pathogen in Texas and Arizona (20,30). The disease is similar to Rhizoctonia root rot in that plants become permanently wilted and black lesions expand rapidly over the beet surface. With Pythium root rot, however, the black discoloration penetrates deep into the interior of the taproot, whereas with Rhizoctonia root rot, symptoms are initially confined primarily to the external surface of the beet.

Generally, all these diseases, with the exception of the seedling pathogen *P. ultimum*, are favored by warm, moist soils. Therefore, cultural practices such

as planting early in spring and limiting irrigation can help reduce early stand losses by delaying infection. Planting of seed that has been primed and/or treated with fungicides can also help to delay infection and to establish vigorous stands (10,18,25,27). Unfortunately, none of these measures controls disease for the entire season.

Genetic resistance may be the most effective and longest lasting control strategy for soilborne pathogens. Although resistance to *P. betae*, the vector of BNYVV, has been found in several sugar beet cultivars (5), resistance to BNYVV appears to be more promising, since the inheritance of resistance is controlled by a single dominant gene and heritability is reasonably high (13,14,33). Breeding for resistance to fungal root rots caused by *Rhizoctonia, Fusarium*, or *Aphanomyces* is much more difficult and complex (1,4,11,12,28). Resistance to these pathogens is multigenic, and the heritabilities are lower than for BNYVV because multigenic inheritance decreases the possibility of obtaining highly resistant cultivars (1,4,11). The presence of minor or modifying genes increases the difficulty of identifying and isolating the major genes for resistance (11).

Because of the availability of a number of rhizomania-tolerant cultivars and a paucity of cultivars possessing resistance to soilborne fungal pathogens, a field study was conducted during 1991–1993 using rhizomania-tolerant cultivars and fumigation with a twofold purpose: 1) to evaluate the performance of rhizomania-tolerant germ plasm when exposed to the Texas root rot complex and 2) to ascertain whether the combination of fumigation and genetic tolerance would improve yield parameters better than either control strategy alone. Preliminary reports have been published (7,9).

MATERIALS AND METHODS

Field preparation and fumigation. Studies were conducted from 1991 to 1993 at the USDA-ARS Conservation and Production Research Laboratory, Bushland, Texas, on land naturally infested with *R. solani, A. cochlioides, F. o. betae*, and BNYVV. Data from 1992 were omitted because of poor stand establishment caused by soil crusting shortly after planting and subsequent plant mortality due to severe disease pressure. The soil was a Pullman silty clay loam (39-32-39, sand-silt-clay, pH 6.3, and O.M. 1.6) (31,32). Field sites differed with regard to previous crops and crop rotations. The 1991 study was on land that had been cropped with sugar beets the previous year. The field used for the 1993 study had been planted with wheat the previous year, and it had been 3 yr since sugar beets had been grown.

In February of each year, fields were listed into beds with 76-cm spacing. Anhydrous ammonia was injected 20 cm deep into each bed at a rate of 170 kg/ha. Soil was sealed with a rolling cultivator and beds were reshaped. Approximately 3 wk prior to planting, 1,3-dicloropropene (Telone II) was injected 40–45 cm deep with a single chisel in the center of each bed at a rate of 93 L/ha. This was accomplished with a fumigation rig (Little Squirt, Reddick Fumigants, Williamston, NC) mounted on a chisel plow. Beds were reshaped and worked with a rolling cultivator and cultipacker immediately after fumigation to seal the soil surface. Ethofumesate (Nortron), 10L/ha, and phorate (Thimet), 130 g/3,300 m of row, were used for weed and insect control, respectively.

Planting. Sugar beet seeds were planted 28 April 1991 and 1 April 1993. Main plots were fumigated or nonfumigated and subplots were cultivars. Fifteen cultivars were planted in a randomized complete block split-plot design with six replications. The entries used in the test consisted of 13 rhizomania-tolerant cultivars and, as checks, two rhizomania-susceptible locally adapted cultivars. The tolerant cultivars were a diverse collection from many different growing areas of the United States and Europe (Table 1). The entire test consisted of 180 four-row plots 8 m long with 76-cm spacing. Entries were seeded at a rate of 30 seeds per meter at a depth of 2 cm and were thinned 6–8 wk later to a uniform stand of 10–12 plants per meter. The 1991 study was preirrigated, followed by two postplant irrigations for emergence. In 1993, one postplant irrigation was applied for emergence. Phenmedipham (Betamix) was sprayed 6 wk after planting at 2.5 L/ha, and for additional weed control, trifluralin (Treflan) was applied after 9 wk as a layby treatment at 1.9 L/ha.

Harvest and data collection. Plots were harvested 15–17 October 1991 and 4–8 October 1993. The two center rows were harvested mechanically with an International Harvester sugar beet digger. Root weights were recorded, and a subsample of 15–20 roots was randomly selected from each plot and rated for disease severity. Disease was rated visually on a scale of 0–4 as follows: *Rhizoctonia*, 0 = no disease, 1 = small, localized lesions with up to 25% of root surface affected, 2 = lesions coalescing with 26–50% of root affected, 3 = 51–75% of root covered with lesions but no internal discoloration, and 4 = more than 75% of beet surface covered with lesions and internal discoloration; *Aphanomyces* and *Fusarium*, 0 = no disease, 1 = less than 25% of vascular elements necrotic or localized lesions on root, 2 = 26–50% vascular necrosis or less than 10% of taproot rotted, 3 = over 50% necrosis of vascular elements and 10–25% of taproot rotted, and 4 = more than 25% of taproot rotted. A disease index (DI) was calculated by the following equation: $DI = (DR1 \cdot 1 + DR2 \cdot 2 + DR3 \cdot 3 + DR4 \cdot 4)/(\Sigma DR0\text{–}4)$, where $DR0$ = number of beets rated 0, $DR1$ = number of beets rated 1, and so on.

The same subsample of beets from each plot that was rated for disease severity was transported to the Imperial Holly Sugar factory in Hereford, Texas, for sucrose determination. The presence of BNYVV from each study was confirmed by sampling symptomatic plants and testing them by enzyme-linked immunosorbent assay (ELISA). In 1991, every plot was sampled and tested on two separate occasions during the season. Because of lack of rhizomania symptoms in 1993, sampling for BNYVV was performed once shortly before harvest.

All data were subjected to analysis of variance for a split-plot test, and treatment means were separated by the LSD and Duncan's multiple range tests. Because of differences between the 2 yr, data are presented separately.

Table 1. Cultivars used in fumigation study, 1991–1993

Cultivar	Source	Location of predominant usage
Tx18[a]	Hilleshög Mono-Hy	Texas
HH67[a]	Holly	Texas
H89779	Spreckels	California
SS462R	Spreckels	California
SS334R	Spreckels	California
Beta 4581	Beta Seed	Idaho
Rhizosen	Holly	California
88I139-03	Holly	United States
Maribo Turbo	American Crystal	Italy
Maribo Record	American Crystal	Italy, France
TxMH1[b]	Hilleshög Mono-Hy	Europe
TxMH2[b]	Hilleshög Mono-Hy	Europe
TxMH3[b]	Hilleshög Mono-Hy	Europe
TxMH4[b]	Hilleshög Mono-Hy	Europe
Rizor	Hilleshög Mono-Hy	Europe

[a] Rhizomania-susceptible checks; all others are rhizomania-tolerant.
[b] Bred for use in Europe but not extensively cultivated.

RESULTS

All yield data were lower in 1991 than in 1993 (Tables 2–4). This was due, in

part, to differences in both disease severity and incidence. Disease severity, in general, was lower in 1993. Incidence of Rhizoctonia root rot and rhizomania was also lower in 1993, whereas that of Fusarium and Aphanomyces root rots was similar for the two tests. However, similar trends appeared during both years. For example, root yield, gross sucrose, and disease index were consistently improved, though not always significantly, in fumigated plots compared with nonfumigated plots (Tables 2 and 3). Percent sucrose and final stand (total number of beets in plot at harvest) were seldom significantly influenced by fumigation. Tx18, a locally adapted cultivar, consistently performed the best during both years for all components evaluated. It also provided the highest yields in the nonfumigated plots (Tables 2 and 3). Maribo Record also improved consistently with fumigation. For both years, HH67 and Maribo Record also responded with significant improvement in yield and gross sucrose in fumigated plots compared with nonfumigated plots (Tables 2 and 3). Those entries that responded least to fumigation included 88I139-03, Rhizosen, Maribo Turbo, and TxMH2. A significant cultivar × fumigation interaction was also observed in both years for a number of entries.

Several entries did not produce similar results in the 2 yr. Rizor, H89779, SS462R, and SS334R were all improved by fumigation in 1993. The disease index was also lowered by fumigation in 1993 across a large number of entries, particularly the European cultivars (Tables 2 and 3). Inexplicably, Beta 4581 and Maribo Turbo responded much more poorly in 1993 than in 1991. However, cultivar differences observed between years were similar regarding root and sucrose yields when expressed as a percentage of fumigated yields to control yields, with the exception of Maribo

Table 2. Yield data and disease index for fumigated (F) and nonfumigated (Ck) sugar beets in 1991

	Root yield (t/ha)		Disease index[a]		% Sucrose		Gross sucrose (t/ha)		Final stand[b]	
Cultivar	F	Ck	F	Ck	F	Ck	F	Ck	F	Ck
Tx18	52.5	41.2	0.7	1.0	13.6	13.4	7.1	5.5	72.2	76.2
HH67	31.1[c]	19.2	1.3	1.3	12.0	11.7	3.6[c]	2.2	63.3	68.7
H89779	24.5[c]	16.8	1.2	1.3	10.9	11.3	2.7	1.9	33.8	31.0
SS462R	14.8	8.2	1.4	1.5	11.4	11.1	1.6	0.8	49.3	46.5
SS334R	18.4	14.3	1.4	1.4	12.0	11.8	2.2	1.6	51.5	56.7
Beta 4581	36.0	26.9	0.9[c]	1.3	12.2	12.3	4.4	3.3	61.8	75.3
Rhizosen	26.9	27.2	1.0	1.2	12.2	12.0	3.3	3.3	56.3	53.0
88I139-03	27.5	22.3	1.0	1.2	11.5	11.8	3.0	2.5	44.8	44.0
Maribo Turbo	32.4	26.7	1.1	1.1	12.0	12.8	3.8	3.3	77.2	79.2
Maribo Record	27.5[c]	17.0	1.4	1.7	11.6	11.7	3.3[c]	1.9	56.7	63.3
TxMH1	25.6	18.7	1.3	1.3	12.6	12.4	3.3	2.2	62.2	56.7
TxMH2	34.4	31.9	1.0	1.2	12.9	12.8	4.4	4.1	74.0	74.0
TxMH3	20.9	15.9	1.1	1.4	12.3	11.6	2.5	1.9	60.7	62.3
TxMH4	37.9	24.2	1.0	1.1	12.1	12.2	4.7	3.0	61.3	75.8
Rizor	28.6	19.2	1.6	1.7	11.4	12.0	3.3	2.5	75.2	82.0
LSD ($P = 0.05$)	11.0	7.7	0.4	0.4	1.0	0.9	1.4	0.8	12.8	12.7

[a]A weighted average of 15–20 beet roots rated individually for severity of disease caused by *Aphanomyces cochlioides*, *Fusarium oxysporum* f. sp. *betae*, and *Rhizoctonia solani* on a 0–4 scale, with 0 = a healthy root and 4 = completely rotted root. The disease index was then calculated by the following equation: $DI = (DR1 \cdot 1 + DR2 \cdot 2 + DR3 \cdot 3 + DR4 \cdot 4)/\Sigma DR0\text{–}4)$, where $DR0$ = number of beets rated 0, $DR1$ = number of beets rated 1, etc.
[b]Total number of beet roots in the plot at harvest.
[c]Significant difference ($P = 0.05$) between fumigated and nonfumigated entries according to Duncan's multiple range test.

Table 3. Yield data and disease index for fumigated (F) and nonfumigated (Ck) sugar beets in 1993

	Root yield (t/ha)		Disease index[a]		% Sucrose		Gross sucrose (t/ha)		Final stand[b]	
Cultivar	F	Ck	F	Ck	F	Ck	F	Ck	F	Ck
Tx18	77.8	57.7	0.7[c]	1.3	14.9[c]	14.1	11.5[c]	8.0	91.0[c]	78.8
HH67	63.5[c]	42.1	0.8[c]	1.3	13.8	13.5	8.8[c]	6.0	91.3	86.0
H89779	43.2	28.9	1.0	1.2	12.7	13.0	5.5	4.1	61.5	46.8
SS462R	35.2[c]	23.4	1.0[c]	1.6	13.2	13.0	4.7	3.0	77.0[c]	64.0
SS334R	52.8	39.9	1.0	1.3	13.7	13.7	7.1[c]	5.5	85.0	74.8
Beta 4581	47.8	46.5	1.1	1.3	13.4	13.5	6.6	6.3	77.0	80.0
Rhizosen	47.3	49.2	1.0	1.1	13.3	13.7	6.3	6.6	66.2[c]	80.8
88I139-03	42.3	31.1	1.3	1.3	12.4	13.0	5.2	4.1	66.8	58.0
Maribo Turbo	33.5	39.2	1.3	1.3	14.3	14.3	4.9	5.8	78.5	80.3
Maribo Record	58.0[c]	34.6	1.0[c]	1.5	14.0	14.6	8.0[c]	4.9	79.8	74.7
TxMH1	37.9	30.8	1.1[c]	1.5	13.7	13.5	5.2	4.1	74.2	62.2
TxMH2	48.7	42.3	1.0	1.0	14.0	14.8	6.9	6.6	100.8	101.7
TxMH3	51.1	37.1	1.0[c]	1.5	14.0	12.8	7.1	4.7	88.3	81.3
TxMH4	53.3	41.2	1.0[c]	1.4	12.1	12.8	6.6	5.2	85.0	85.5
Rizor	64.6[c]	43.4	0.9[c]	1.3	13.7	14.0	8.8	6.0	87.5	82.2
LSD ($P = 0.05$)	12.1	10.2	0.2	0.3	1.3	1.1	1.6	1.4	10.9	12.7

[a]A weighted average of 15–20 beet roots rated individually for severity of disease caused by *Aphanomyces cochlioides*, *Fusarium oxysporum* f. sp. *betae*, and *Rhizoctonia solani* on a 0–4 scale, with 0 = a healthy root and 4 = completely rotted root. The disease index was then calculated by the following equation: $DI = (DR1 \cdot 1 + DR2 \cdot 2 + DR3 \cdot 3 + DR4 \cdot 4)/\Sigma DR0\text{–}4)$, where $DR0$ = number of beets rated 0, $DR1$ = number of beets rated 1, etc.
[b]Total number of beet roots in the plot at harvest.
[c]Significant difference ($P = 0.05$) between fumigated and nonfumigated entries according to Duncan's multiple range test.

Turbo and Beta 4581 (Table 4).

The disease index was a weighted average of harvested beet roots from each plot rated individually for disease severity. It represented ratings made for *R. solani, A. cochlioides*, and *F. o. betae*. *Pythium* spp. were present in the plots but were not factors in yield reductions. BNYVV was detected in both studies, but the incidence was lower in 1993.

Table 5 gives estimates of the net return of each cultivar in fumigated and nonfumigated plots. Calculations were based on the payment given to growers for beets containing 14% sucrose, which is the Texas average. The net return by fumigation compared with the control was based on the estimated cost of $250/ha for cost of the chemical.

DISCUSSION

Fumigation has previously been evaluated for control of soilborne pathogens of sugar beets (2,15,22,23). However, many fumigants are not always economically practical. Telone II was chosen as the fumigant for the current study because of its cost efficiency and effectiveness at lower rates.

Telone II has been shown to be effective in reducing root rot and increasing yields in fields infested with *A. cochlioides* and *F. o. betae*. It has little or no effect on Rhizoctonia root and crown rot (22). The reason for this is not known. Telone II has also been effective in reducing losses to rhizomania. With rhizomania, only primary tissues, such as epidermal and cortical tissues of sugar beet, are susceptible to infection by *P. betae*. Telone II possibly reduces soil populations of *P. betae* to low levels, protecting the taproot until secondary growth begins (6). Delaying infection for 9–11 wk after planting has been shown to be critical for preventing yield reductions due to rhizomania (15).

The combination of fumigation and rhizomania-tolerant cultivars has been tried in California for rhizomania control (2), while the combination of fumigation and root-rot-tolerant cultivars has been evaluated in Texas for reducing disease losses to fungal pathogens (22,23). It was unknown whether rhizomania-tolerant cultivars and fumigation with Telone II in combination would control the multiple soilborne pathogens in the Texas root disease complex. The present study was conducted in the attempt to answer this question.

There was no reason to expect the rhizomania-tolerant cultivars to have any tolerance to the fungal root rots. They were used in the test because a number of them are available commercially and because rhizomania is one of the diseases present in the root rot complex. A fumigation × cultivar interaction was not expected, however. Since none of these prior studies mentioned a fumigation × cultivar interaction, this is the first report we are aware of in which this observation has been made. Table 5 corroborates this interaction by demonstrating the different economic returns obtained for the various entries with and without fumigation.

Large differences in yield were observed between the two studies. We speculate these differences were caused by higher disease pressure in 1991, which can be explained primarily by cultural practices. The 1991 study was preirrigated, was planted late (28 April) on land cropped the previous year with sugar beets, and was irrigated twice for emergence. These practices were to enhance disease pressure, but the conditions created in 1991 were so severe that cultivar tolerance to BNYVV in some entries was possibly overcome.

The 1993 study more accurately reflected a Texas sugar beet grower's practices and contributed toward a more realistic evaluation of the cultivars' responses to disease. The test was seeded on land with at least a 3-yr absence from sugar beets. The study was planted early (1 April) on land cropped the previous year with wheat, and one irrigation was applied for sugar beet emergence.

The observation that disease pressure was greater in 1991 than in 1993 is supported by the yields collected during both studies (Tables 2 and 3). All yield components (root weight, percent sucrose, gross sucrose, and final stand), with the exception of disease index, are higher in 1993. The disease index was very similar in the 2 yr because the subsample of beets chosen for disease ratings was selected randomly from the plots after mechanical harvesting. Many of the severely infected plants, which would have raised the disease index, were so small that they fell through the digger chains while being harvested and could not be collected.

Table 4. Improvement of yield components with fumigation by year for each cultivar on a percentage basis[a]

	Yield (t/ha)		Gross sucrose (t/ha)	
Cultivar	1991	1993	1991	1993
Tx18	22	26	23	30
HH67	38	34	39	32
H89779	32	33	30	26
SS462R	45	34	50	36
SS334R	22	25	27	23
Beta 4581	25	3	25	5
Rhizosen	−1	−4	0	−5
88I139-03	19	27	17	21
Maribo Turbo	18	−15	13	−16
Maribo Record	38	40	43	39
TxMH1	27	19	33	21
TxMH2	7	13	7	6
TxMH3	24	27	24	34
TxMH4	36	23	36	21
Rizor	33	33	24	32

[a] Values represent percent improvement of fumigated yields compared with checks.

Table 5. Estimate of economic return after fumigation with Telone II for 15 sugar beet cultivars in 1991 and 1993[a]

	1991			1993		
	Return[b] ($/ha)		Net return by fumigation[c]	Return ($/ha)		Net return by fumigation
Cultivar	F	Ck	($/ha)	F	Ck	($/ha)
Tx18	1,837	1,442	145	2,723	2,019	454
HH67	1,088	672	166	2,222	1,473	499
H89779	857	588	19	1,512	1,011	251
SS462R	518	287	−19	1,232	819	163
SS334R	644	500	−106	1,848	1,396	202
Beta 4581	1,260	941	69	1,673	1,627	−204
Rhizosen	941	952	−261	1,655	1,722	−317
88I139-03	962	780	−68	1,480	1,088	142
Maribo Turbo	1,134	934	−50	1,172	1,372	−450
Maribo Record	962	595	117	2,030	1,211	569
TxMH1	896	654	−8	1,326	1,078	−2
TxMH2	1,204	1,116	−162	1,704	1,480	−26
TxMH3	731	556	−75	1,788	1,298	240
TxMH4	1,326	847	229	1,865	1,442	173
Rizor	1,001	672	79	2,261	1,519	492

[a] F = fumigated, Ck = check.
[b] Payment based on 14% sugar ($35/t).
[c] Net return above control plots based on cost of $250/ha for fumigant.

In addition to less disease pressure in 1993, the incidence of rhizomania and Rhizoctonia root rot was lower (*personal observations*). ELISA detected BNYVV in both studies, but fewer plants throughout the field were infected with BNYVV in 1993 than in 1991. Often, final stand is indicative of the *R. solani* levels in fields at harvest. The higher number of beets in the plots in 1993 than in 1991 suggests reduced levels of Rhizoctonia root rot in 1993, since *Aphanomyces* and *Fusarium* usually do not kill the plants, while *Rhizoctonia* often does late in the season.

The locally adapted cultivars Tx18 and HH67 performed best in these tests. Tx18 has been a high-yielding, widely grown cultivar in Texas for years, even in diseased fields. It outperformed the *R. solani*-resistant HH67 in most categories, and its unfumigated yields were better than the fumigated yields of most cultivars in the test. On the basis of these data, Tx18 appears to possess some field tolerance to pathogens in the Texas root rot complex. Several entries in this study, including Rhizosen, failed to improve with fumigation. Rhizosen has been bred for and used successfully in California to control rhizomania, yet it responded poorly to fumigation and the root rot complex in Texas under the conditions of this study. It is a good example of successful use of a cultivar in one location but not in another.

Most of the rhizomania-tolerant cultivars were not outstanding in terms of yield improvement due to fumigation. This may more likely reflect their lack of adaptability to Texas growing conditions than to a poor fumigation response. Maribo Record, however, was an exception. Although it is a European cultivar, it performed almost as well as Tx18 and HH67 in both years. It is used commercially in Italy and France and has strong resistance to rhizomania. It was especially impressive in its response of increasing root yields and gross sucrose compared with the checks. This suggests that it possesses some tolerance to Rhizoctonia root rot, in addition to rhizomania. It may also be susceptible to *Fusarium* and *Aphanomyces*, since fumigation is effective for controlling these two diseases. Another reason for the failure to improve sucrose percentage with fumigation and the relatively poor performances of the rhizomania-tolerant cultivars could be that rhizomania had little or no effect on yields in this study. It is possible that the tolerant cultivars may have performed better relative to Tx18 and HH67 had rhizomania pressure been greater.

Typical yields in Texas average 60 t/ha with 14% sugar. In 1993, the top five entries in this test met or exceeded these values in the fumigated plots under very severe disease conditions (Table 3). Responses in the 1991 study were not as good as those in 1993, but responses to fumigation were similar in both years when expressed as percent yield increase of fumigation over check (Table 4). The combination of fumigation and genetic tolerance to rhizomania seems to be less effective for reducing losses in the Texas root rot complex than fumigation and use of locally adapted cultivars. Fumigation appears to have the potential to benefit Texas growers, but it will not be sufficient alone to provide an economically acceptable yield. It still is important to use fumigation in an integrated control strategy. Other practices, including the use of appropriate cultivars, early planting, water management, and lengthening of rotations between sugar beet plantings, will increase the probability of fumigation being successful.

Finally, it is critical for new cultivars to be developed with multiple disease tolerance specifically for Texas growing conditions. Most of the diseases in the Texas root rot complex require similar development conditions, so planting cultivars with resistance to only one pathogen will not be sufficient. Each pathogen can seriously reduce yields independently (8,16,19,24,33). The Spreckels cultivars SS334R, SS462R, and H89779 and the Holly cultivar Rhizosen have been bred for and used primarily in California. Although they performed better in 1993 than in 1991, their yields were still unacceptable for Texas under the extreme conditions of this test. These observations, plus the success of Tx18 and HH67 in both years of this study, further demonstrate the importance of producing and using cultivars with regionally adapted traits.

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