Strawberry Black Root Rot and Berry Yield Are Not Affected by Terbacil Herbicide

Todd L. Mervosh[1] and James A. LaMondia[2]

The Connecticut Agricultural Experiment Station, Valley Laboratory, 153 Cook Hill Road, P.O. Box 248, Windsor, CT 06095

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Abstract. **The effects of terbacil herbicide on strawberry (*Fragaria ×ananassa* Duch. 'Honeoye') yield and black root rot disease were determined in field plots at two locations in Connecticut over 4 years. Terbacil treatments at up to four times the maximum label dosage caused some temporary foliar chlorosis but did not affect the health of structural or perennial roots and associated feeder roots. Development of secondary root growth (perennial roots) was not influenced by terbacil. Terbacil had no effect on the quantity of lesion nematodes [*Pratylenchus penetrans* (Cobb) Filip & Schur. Stek.] extracted or the amount of the fungal pathogen *Rhizoctonia fragariae* Husain and McKeen isolated from strawberry roots. At both locations, *R. fragariae* was common on plant roots by the fourth year. Terbacil treatments did not affect strawberry yields in terms of number or weight of ripe berries per plot. Our results indicate that terbacil does not contribute to black root rot or decreased yields in 'Honeoye' strawberry. Chemical name used: 5-chloro-3-(1,1-dimethylethyl)-6-methyl-2,4-(1*H*,3*H*)-pyrimidinedione (terbacil).**

The herbicide terbacil (Sinbar 80WP; E.I. du Pont de Nemours & Co., Wilmington, Del.) is often used in strawberry (*Fragaria ×ananassa*) production for early postemergence and residual preemergence weed control. Other than 2,4-D, terbacil is the only herbicide registered for use in strawberries that controls a wide range of broadleaf weeds (Bonanno, 2003). However, in response to grower complaints that terbacil injured strawberries in some situations, DuPont removed strawberries from the Sinbar product label in 1991, and issued a supplemental Sinbar label for strawberries (DuPont Agricultural Products, 1991). This supplemental label, in effect when field research for this paper was conducted, set a maximum annual application rate of 0.56 kg·ha⁻¹ of product (0.45 kg·ha⁻¹ of terbacil) for strawberries. Terbacil could not be applied to soils containing <2% organic matter and could not be applied until plants had been established in the field for at least 6 months. In addition, terbacil could only be applied at two specific times: to dormant plants in late fall, and after postharvest renovation before new leaf growth (DuPont Agricultural Products, 1991).

Some studies have reported that terbacil reduced strawberry vigor or berry yield. However, in all of these cases injury occurred when terbacil was applied at rates of 0.56 kg·ha⁻¹ a.i. or higher to newly planted strawberries or during the transplant year (Ahrens, 1982; Doohan et al., 1993; Masiunas and Weller, 1986; Weller, 1984). We found no reports of terbacil causing

significant injury to strawberries when applied according to the use directions on the 1991 supplemental label for Sinbar.

Strawberry black root rot is a serious disease that is characterized by blackening of roots and associated poor growth and yield (Maas, 1984). Black root rot of perennial strawberries is described as a complex root cortical disease caused by the binucleate fungus *Rhizoctonia fragariae* (Martin, 1988; Wilhelm et al., 1972). The lesion nematode *Pratylenchus penetrans* has been associated with increased severity of black root rot (Chen and Rich, 1962; Goheen and Bailey, 1955; Goheen and Smith, 1956; LaMondia, 1994; LaMondia, 2002; LaMondia and Martin, 1989; Riggs et al., 1956). The mechanism by which *P. penetrans* affects development of black root rot is unknown. However, the effect appears to be local rather than systemic because *R. fragariae* infection is higher in and near nematode lesions but not at distant areas on the root or on other roots (LaMondia, 2003).

The morphology of strawberry roots may contribute to the difficulty in understanding black root rot. Three distinct types of roots exist on crowns at the same time, and the relative abundance of each morphological type varies with time (Wilhelm and Nelson, 1970). New structural roots (perennial roots) are produced from crowns. The terminal branches of these roots are fine lateral or feeder roots. These feeder roots do not develop secondary tissues and have a limited life span, and may be replaced several times each season. The structural roots develop suberized secondary tissues and eventually become dark or black perennial roots due to the collapse of epidermal and cortical cells. These roots appear to be diseased but may be functional and healthy, despite loss of the cortex. Perennial roots act as storage organs and conduct water without mineral uptake. All these root types

have specific functions and are necessary for the growth and survival of the strawberry crown. Lesion nematode symptoms are commonly seen on young structural roots. Nematode infection may reduce overall root growth, stimulate suberized root production, or change the balance between root types, influencing strawberry growth and vigor (Wilhelm and Nelson, 1970).

We have found that *R. fragariae* is commonly resident on the sloughed cortex of healthy perennial roots (LaMondia, 2003; LaMondia and Martin, 1989). From this source, the fungus may then infect structural or feeder roots, especially when the plant is under stress or when roots are damaged. Lesion nematodes aggregate in the root cortex. Direct effects of nematode feeding and movement are cell damage and death. Indirect effects of nematode infection are discoloration of the endodermis and early polyderm formation, which results in localized areas of secondary growth and cortical cell weakening or death. Cells weakened by *P. penetrans* are more susceptible to *R. fragariae*, leading to increased infection and cortical root rot (LaMondia and Martin, 1989).

Strawberry black root rot has been associated with a number of other pathogens and environmental conditions (Wilhelm, 1984; Wing et al., 1994). Either directly or indirectly, factors such as soil texture, moisture, temperature, and soil compaction are often associated with strawberry black root rot (Maas, 1984; Wing et al., 1994).

A 1992 survey of 27 strawberry growers in New York found a correlation ($P < 0.01$, $r^2 = 0.26$) between terbacil application rate and a lack of healthy feeder roots (Wing et al., 1995). The use of other herbicides was not associated with strawberry root health. Other factors negatively correlated with root health were soil compaction, fine soil texture, absence of raised beds, non-use of fungicides, soil fumigation, advanced age of planting, and cumulative years of strawberry monoculture (Wing et al., 1995). The authors stated that no single factor represented a major part of the variation in root health ratings. Thus, they suggested several interacting factors were necessary to cause strawberry black root rot (Wing et al., 1995), a view consistent with that of Wilhelm (1984) who characterized black root rot as a disease complex.

No scientific studies have been published to investigate terbacil effects on strawberry root health and black root rot development. Our objectives were to examine the effects of repeated terbacil treatments on the prevalence of root rot symptoms and black root rot pathogens, overall strawberry vigor, and berry yield. An experiment in which all factors are kept equal except for terbacil dosage is important to determine if a causal relationship exists between use of terbacil and strawberry black root rot. Strawberry growers need to know if this herbicide poses a risk to their crop.

Materials and Methods

The experiment was conducted at research farms of The Connecticut Agricultural Experiment Station in Windsor and Hamden, Conn. Soil type in Windsor was Merrimac sandy

loam (sandy, mixed, mesic Typic Dystrochrept; 73.4% sand, 22.3% silt, 4.3% clay, pH 5.9, 1.2% organic matter after sieving through a 2-mm screen), and in Hamden was Yalesville fine sandy loam (coarse-loamy, mixed, mesic Typic Dystrochrept; 56.4% sand, 30.8% silt, 12.8% clay, pH 6.1, 1.4% organic matter after sieving through a 2-mm screen). Crowns of 'Honeoye' strawberry were planted in freshly tilled soil at both locations in early May 1996. Plot size was 1.53 m by 1.83 m. Twenty-one crowns were planted in each plot (three rows of seven). In-row spacing was 0.15 m, and rows were 0.61 m apart.

The experiment was arranged as a 4 × 2 factorial design with four terbacil treatments at two locations. Treatments were replicated three times, and the experiment was evaluated over 4 years. Treatments consisted of an untreated check (no terbacil), and three dosages of terbacil (applied as Sinbar 80WP): 0.45, 0.9 and 1.8 kg·ha⁻¹ a.i. per year, half of which was applied in July (after renovation) and half in November (to dormant plants). According to the Sinbar supplemental label for use in strawberries (DuPont Agricultural Products, 1991), these terbacil dosages were equivalent to one, two and four times the maximum amount allowed per year. However, the soil organic matter content at both locations was <2%, thus according to this label, terbacil use would not have been allowed in these fields.

Herbicide treatments were applied with a hand-held spray boom equipped with three nozzles (8003VS tips) spaced 48 cm apart. Spray bottles were pressurized to 152 kPa with a CO_2 tank, and spray volume was 234 L·ha⁻¹.

Plots were maintained in a weed-free condition so weeds would not affect strawberry yields or pathogen populations. DCPA (Dacthal W-75) and napropamide (Devrinol 50-DF) are widely used herbicides in commercial strawberry production, and strawberries are highly tolerant of both herbicides (Ahrens, 1982; Bonanno, 2003). Within 2 d after planting, all plots were sprayed with DCPA at 6.7 kg·ha⁻¹ a.i. (Windsor) and 10.1 kg·ha⁻¹ a.i. (Hamden) to prevent many annual weeds. Weeds that emerged were removed periodically by hand or hoe. After removing weeds and cutting strawberry runners on 6 Sept. 1996, all plots were sprayed with napropamide at 3.4 kg·ha⁻¹

a.i. (Windsor) and 4.5 kg·ha⁻¹ a.i. (Hamden).

The first terbacil treatments (one-half the annual treatment dosages) were applied to specific plots on 6 Nov. 1996 at both locations. By this date, strawberry leaves had turned red, and the plants were considered dormant. All plots were covered with straw mulch in late November.

At both sites in 1997 and 1998, DCPA was applied at 10.1 kg·ha⁻¹ a.i. in late April or early May, and napropamide was applied at 2.2 kg·ha⁻¹ a.i. in July and again in November. At both sites in 1999, napropamide was applied at 3.4 kg·ha⁻¹ a.i. on 15 Apr.

In 1997, terbacil treatments were applied on 25 July at both sites and on 13 Nov. (Windsor) and 20 Nov. (Hamden). In 1998, terbacil treatments were applied at both sites on 14 July and on 13 Nov.

Ripe berries were picked from plots every 2 to 3 d during harvest in 1997, 1998, and 1999. On each harvest date, berry numbers and weights were recorded.

Disease, root and soil assays. Two crowns per plot were sampled annually. Crowns were sampled at the Windsor site on 5 Nov. 1996, 9 Oct. 1997, 24 Sept. 1998, and 24 Sept. 1999. Crowns were sampled at the Hamden site on 5 Nov. 1996, 17 Oct. 1997, 24 Sept. 1998, and 6 Oct. 1999. Loose soil was removed, and entire root systems were washed free of soil. Shoot and root weights were recorded. Root systems were separated into structural roots and black suberized perennial roots, each with attached fine lateral (feeder) roots. Two people recorded independent ratings of the percent diseased roots of each type, and values were averaged. Black perennial roots were determined to be diseased if the roots were soft or collapsed. Nematodes were extracted from 2 g structural and feeder root tissue placed in a flask containing 50 mL water, shaken for 7 d using a wrist-action shaker and counted (Barker, 1985). In 1996, 1997, and 1999, *R. fragariae* was isolated from eight or ten 1.0-cm sections of surface sterilized roots (exposed to 0.5% NaOCl for 30 s) that were placed on acidified water agar for 48 h. *R. fragariae* identity was confirmed by microscopic observation or by culture on half-strength potato dextrose agar. Data was expressed as the percentage of root sections colonized by *R. fragariae*.

Berry yield data and disease data were

subjected to analysis of variance–general linear model procedure (GLM ANOVA) with year as a nested variable ($P = 0.05$) [Number Cruncher Statistical Systems, Kaysville, Utah].

Results

Terbacil applied at up to four times the maximum labeled dosage did not affect the health of structural or perennial roots and associated feeder roots of strawberries (Table 1). The extent of typical black root rot symptoms on structural roots was higher at Windsor than at Hamden ($P = 0.01$), and disease levels on perennial roots increased over time. The percentage of the root system that developed secondary growth was not influenced by terbacil, but a significant interaction between terbacil dosage and location was observed ($P = 0.04$).

Extraction of *P. penetrans* and isolation of *R. fragariae* from strawberry roots was not affected by terbacil dosage (Table 2). Nematode numbers were consistently higher in Windsor than in Hamden ($P < 0.001$), and varied between years. *R. fragariae* was common on roots at both locations by 1999.

Terbacil treatments did not affect strawberry yields, in terms of number or weight of ripe berries harvested (Table 3). Temporary leaf chlorosis was observed on some plants treated with the highest terbacil dosage (1.8 kg·ha⁻¹ a.i. per year), but berry yield was not reduced. Strawberry yields were greater in Hamden than in Windsor ($P < 0.001$). Plants were more vigorous in Hamden than in Windsor, especially by 1999 (data not shown).

Discussion

Black root rot symptoms were more prevalent at the Windsor location, despite no significant differences in *R. fragariae* isolation between locations. Greater disease incidence may be due to higher *P. penetrans* numbers in Windsor than in Hamden. These results support the role of the lesion nematode in increasing severity of strawberry black root rot (Chen and Rich, 1962; Goheen and Bailey, 1955; Goheen and Smith, 1956; LaMondia, 1994; LaMondia, 2002; LaMondia and Martin, 1989; Riggs et al., 1956).

The survey of strawberry growers in New York identified a correlation between terbacil

Table 1. Effects of terbacil application rate on strawberry root composition and percent black root rot in field plots in Windsor and Hamden, Conn.

Location	Terbacil (kg·ha⁻¹·yr⁻¹)	Percent secondary roots				Percent diseased structural root				Percent diseased perennial root			
		1996	1997	1998	1999	1996	1997	1998	1999	1996	1997	1998	1999
Windsor	0	0	NDᶻ	89.5	81.7	10.3	15.6	19.8	5.0	ND	6.7	39.2	75.0
	0.45	0	ND	94.0	66.7	9.2	11.7	27.7	16.7	ND	8.3	51.7	70.0
	0.9	0	ND	80.3	78.3	13.9	8.9	20.3	10.0	ND	6.7	40.8	80.0
	1.8	0	ND	72.0	56.7	15.4	8.9	20.3	11.7	ND	7.8	20.8	60.0
Hamden	0	0	ND	80.8	70.0	4.0	6.0	11.3	8.3	ND	13.5	33.3	75.0
	0.45	0	ND	87.7	70.0	2.7	10.3	20.5	5.0	ND	11.3	31.2	48.3
	0.9	0	ND	55.0	73.3	4.2	11.3	6.5	6.7	ND	13.0	36.7	75.0
	1.8	0	ND	77.5	75.0	3.1	9.2	7.8	5.0	ND	13.3	31.7	65.0
Source (ANOVA)		*P* = percent secondary roots				*P* = diseased structural root				*P* = diseased perennial root			
Terbacil treatment		NS				NS				NS			
Location		NS				0.01				NS			
Terbacil × location		0.04				NS				NS			

ᶻND = analysis not done.
ᴺˢNonsignificant.

Table 2. Effects of terbacil application rate on isolation of strawberry black root rot pathogens *Pratylenchus penetrans* and *Rhizoctonia fragariae* from strawberry roots in field plots in Windsor and Hamden, Conn.

Location	Terbacil (kg·ha⁻¹·yr⁻¹)	*Pratylenchus* per 2 g root				Percent root sections with *Rhizoctonia*			
		1996	1997	1998	1999	1996	1997	1998	1999
Windsor	0	53.3	25.3	25.0	72.5	0.0	4.2	ND[z]	21.7
	0.45	130.0	7.7	20.0	22.5	16.7	12.5	ND	15.0
	0.9	70.0	13.0	45.0	80.0	8.3	4.2	ND	16.7
	1.8	95.0	9.0	105.0	110.0	0.0	4.2	ND	13.3
Hamden	0	35.0	0.3	0.0	7.5	0.0	8.3	ND	35.0
	0.45	15.0	1.0	0.0	5.0	0.0	8.3	ND	35.0
	0.9	0.0	2.3	5.0	20.0	8.3	8.3	ND	41.7
	1.8	23.3	15.3	0.0	10.0	0.0	4.2	ND	41.7
Source (ANOVA)		*P* = *Pratylenchus* per 2 g root				*P* = root sections with *Rhizoctonia*			
Terbacil treatment		NS				NS			
Location		0.001				NS			
Terbacil × location		NS				NS			

[z]ND = analysis not done.
NSNonsignificant.

Table 3. Effects of terbacil application rate on number and weight of strawberries harvested from field plots in Windsor and Hamden, Conn.

Location	Terbacil (kg·ha⁻¹·yr⁻¹)	Total berry yield							
		(no./plant)				(g/plant)			
		1997	1998	1999	Total	1997	1998	1999	Total
Windsor	0	18.0	34.1	17.5	69.6	161.4	193.9	57.0	412.3
	0.45	24.0	32.7	17.9	74.5	204.7	160.4	67.9	433.0
	0.9	18.5	39.8	21.0	79.4	169.5	254.2	74.0	497.7
	1.8	21.5	34.5	20.2	76.1	176.2	216.1	70.1	462.4
Hamden	0	29.9	43.2	51.1	124.2	245.5	247.9	215.3	708.8
	0.45	34.1	44.4	41.4	120.0	299.0	253.7	168.6	721.2
	0.9	29.3	46.6	61.0	136.9	254.4	287.0	289.2	830.7
	1.8	26.8	48.1	58.3	133.2	240.4	291.3	253.0	784.6
Source (ANOVA)		*P* = berry number				*P* = berry weight			
Terbacil treatment		NS				NS			
Location		0.001				0.001			
Terbacil × location		NS				NS			

NSNonsignificant.

application rate and reduction in healthy feeder roots (Wing et al., 1995). As a result, the authors suggested high levels of terbacil might predispose plants to black root rot. Our experimental results do not support that hypothesis.

Terbacil is a root-absorbed photosynthesis inhibitor that is translocated to the leaves where it can cause chlorosis (Masiunas and Weller, 1986; Vencill, 2002). In our study, terbacil applied at four times the maximum labeled rate to strawberry plants in low organic matter soils caused temporary leaf chlorosis. However, terbacil treatments did not increase black root rot symptoms or reduce berry yields. 'Honeoye', the cultivar evaluated, has average susceptibility to terbacil relative to other strawberry cultivars (Masiunas and Weller, 1986). Fields at both sites were naturally infested with black root rot pathogens.

A causal relationship linking a herbicide and a disease cannot be established through a simple correlation analysis. Other explanations are possible for the association of terbacil with strawberry black root rot reported by Wing et al. (1995), who found several other physical and cultural factors were correlated with poor root health. For example, use of herbicides such as terbacil may allow growers to extend the productive life of strawberry plantings additional years, making eventual development of root diseases more likely. Additionally, weed populations often become more competitive in aging strawberry plantings, so growers are more likely to apply terbacil to older, weedy strawberry fields that are declining from black root rot than to vigorous new plantings.

In 2002 (after field research for this paper was complete), DuPont revised the supplemental label for Sinbar to allow application to soils containing at least 0.5% organic matter (DuPont Crop Protection, 2002). For coarse-textured soils (sands, sandy loams) with 0.5% to 1% organic matter, the maximum annual dosage is 0.42 kg·ha⁻¹ of product (0.34 kg·ha⁻¹ of terbacil), and no more than half this dosage can be applied at one time. For coarse-textured soils with 1% to 2% organic matter and for medium- and fine-textured soils with 0.5% to 2% organic matter, the maximum annual dosage is 0.56 kg·ha⁻¹ of product, and no more than half this dosage can be applied at one time. For established strawberry plantings in soils containing >2% organic matter, up to 0.56 kg·ha⁻¹ of product can be applied at postharvest renovation and again in late fall (DuPont Crop Protection, 2002).

Because the soils used in our study contained between 1% and 2% organic matter, terbacil use is now allowed in these soils at a maximum annual dosage of 0.56 kg·ha⁻¹ of product (0.45 kg·ha⁻¹ of terbacil). Thus, the terbacil application rates in our study were equivalent to one, two and four times the labeled dosages for Sinbar use in strawberries.

Another change in the supplemental label is that Sinbar can now be applied after transplanting strawberries in a matted-row production system at rates of 0.14 to 0.21 kg·ha⁻¹ of product (DuPont Crop Protection, 2002). Application must occur before new runner plants start to root, and prior to new foliage growth.

Our results indicate that strawberry growers can utilize terbacil according to label directions without contributing to risk of black root rot or reduced berry yields. Of course, some variation exists in sensitivity of strawberry cultivars to terbacil, so growers should be careful not to exceed application rates specified for their soil type. Management of black root rot should focus on the pathogens causing the disease and on minimizing cultural practices and environmental conditions that increase disease severity.

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