IMPACTS OF ALTERNATIVES ON STRAWBERRY YIELD AND ROOT COLONIZATION BY FUNGAL PATHOGENS.

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Strawberry production is an important source of income for growers in NC and surrounding states. Currently, our industry employs an annual plasticulture system and an estimated 80% of this acreage is dependent on the soil fumigant, methyl bromide (MB) for the control of a wide array of pests. Root rot pathogens, including *Pythium, Rhizoctonia*, and *Phytophthora*, can seriously reduce yields in strawberry production (Abad et al. 1999, 2002; Martin, 2000). Plants grown under stressful environmental conditions are particularly predisposed to infection and disease development (Abad et al. 1999; Wing et al., 1994). With the pending phase out of MB from the market, an increase in root rot diseases is likely to occur since the wide majority of annual strawberry production systems rely on this fumigant to control soilborne pathogens. In the Southeastern states (NC, SC, GA, VA), for example, strawberry growers will lose an estimated 15% to 20% of their income or $3-4 million per year (Carpenter 2000; Osteen 1999).

We have implemented an aggressive, multi-state and interdisciplinary program to evaluate methyl bromide alternatives for management of soilborne pathogens and weeds in strawberry production fields. As a component of this program, pre-plant soil treatments were evaluated in replicated research station trials during two growing seasons (2000-2002) at three locations; Clayton, NC, Plymouth, NC and Vidalia, GA. At each site, plots consisted of 1(Clayton, Vidalia) or 3 (Plymouth), 6 in. raised, 27 in. wide, plastic mulched beds on 60 in. centers. Plants were spaced 12 to 14 in. apart and staggered in two rows 12 in. apart. Strawberry yield and fruit quality data were collected for comparison of soil treatments. Fruit were harvested at least weekly for 8-10 weeks according to conventional grower's practices (yield results are detailed in Ferguson et al. 2002). Plant growth parameters were also measured including leaf area (cm^3) and dry weights (g) of leaves, roots, fruit/flowers, and crowns. The effectiveness of control of weed growth through plant holes in the plastic mulch was also evaluated in these studies. Standard annual strawberry production and pest management practices recommended for the southeastern US were followed.

Roots were evaluated for black root rot (BRR) symptoms (% area affected), and scored for root health (0= rat-tailed roots with no root hairs to 10 = all primary roots have abundant root hairs). This was complemented with isolations of soilborne fungi and stramenopiles from strawberry roots pre-plant and at regular intervals during the growing season for identification (at least to genus) and later pathogenicity testing. Fungi and stramenopiles were isolated from surface-disinfested strawberry root lesions. Four or five lesions per sampled plant were

plated on two semi-selective culture media (AWA and PARP). Our objective was to evaluate the initial level of colonization by pathogens on incoming transplants and to determine the effectiveness of MB alternatives to control root and crown diseases.

The predominant soilborne fungal pathogen species associated with black root rot of strawberry were *Rhizoctonia fragariae, Phytophthora cactorum*, and several other *Phytophthora, Pythium*, and *Fusarium* spp. Frequencies of organisms colonizing strawberry lesions varied among plant sources. Different pathogen groups predominated at different locations among seasons. Not all fungi or stramenopiles isolated are shown in summary tables 1, 2 and 3. Other organisms were isolated at very low frequencies. Species such as *Alternaria* and *Trichoderma* were also commonly associated with sampled strawberry roots. The primary weed pests at each of these locations included winter annuals such as hairy vetch and henbit and spring annuals or perennial weeds such as portulaca and nutsedge. The numbers and distribution of these weeds varied by location and are not detailed here.

PLYMOUTH NC TRIALS:

At the Vernon James Research and Extension Center in Plymouth, NC, soil treatments applied in 2000-01 season were repeated in 2001-02 in the same field positions, to examine the cumulative effects of treatments over time. The following treatments were tested, after growing a mixed grass/legume cover crop (flail-mowed and tilled in) and prior to planting 'Camarosa': Chloropicrin (12 gal/treated A), compost (30 yd^3/A), non-fumigated control, methyl bromide:chloropicrin (MB) 67:33 (400 lbs/A), Telone-C35 (35 gal/A), InLine (drip applied at 35 gal/A, 1 tape), Telone II (22 gal/A), metam sodium (75 gal/A), metam sodium (drip applied at 75 gal/A, 1 tape). In 2000-2001 strawberry plants were sampled at full-bloom and final harvest from plots treated with different alternatives to methyl bromide for pathogen isolation and identification, as described above. During the field season 2001-2002 strawberry plants were sampled pre-plant (arbitrary trays of plug plants), full-bloom, and at final harvest from treated plots for assay.

In 2000-2001, the non-fumigated control, compost- and Telone II-treated plots produced lower marketable yields than MB. All others were statistically equivalent to MB (Ferguson et al. 2002). In 2001-02 only the non-fumigated control plots and the InLine treated plots produced significantly lower yields than MB (Ferguson et al. 2002). Several different species of fungi and stramenopiles were associated with strawberry root lesions both prior to planting and after field setting (Table 1). Significant effects of pre-plant soil treatments on the frequency of pathogen isolations at Plymouth were limited to *Pythium* sp. (full-bloom) and *R. fragariae* (final harvest) in 2000-2001 (Fig. 1). Although isolation frequencies of *Pythium* spp. were highest in compost-treated plots, there were no significant differences in root rot severity among the soil treatments at full-bloom in 2000-2001 (Fig. 1). Isolation frequency of *R. fragariae* was low preplant (2001-2002) and during both field seasons. No other significant effects on pathogens were noted. Soil treatments impacted root health parameters at full-bloom 2000-2001

and final harvest 2001-2002 (Table 1). Specific treatment effects are not detailed here.

CLAYTON, NC:
Pre-plant soil treatments at the Central Crops Research Station in Clayton, NC were implemented prior to planting 'Chandler' in 2000-2001 and in an adjacent field in 2001-02. Clayton soil treatments consisted of: MB 67:33 (400 lbs/treated A), Iodomethane (IM) 100% (250 lbs/A), Iodomethane:chloropicrin 60:40 (300 lbs/A), Telone-C35 (28 gal/A) and InLine (drip applied at 28 gal/A) in the 2000-01 season with a minor change to IM:chloropicrin 75:25 (276 lbs/A) replacing the 60:40 mixture in 2001-02 season.

In the 2000-2001 trial, marketable yields comparable to MB ($P = 0.05$) were obtained in Telone-C35, InLine, metam sodium (drip and shank), chloropicrin, IM 100% and IM:chloropicrin 60:40 –treated plots (data not shown). In 2001-2002 all treatments were equivalent to MB-treated plots (Ferguson et al. 2002). Strawberry plants were sampled from plots treated with different alternatives to methyl bromide for pathogen isolation and identification at full-bloom and final harvest in 2000-2001 and pre-plant and full-bloom in 2001-2002 (Table 2). Soil treatments affected isolation frequencies of *Pythium* spp. and *Trichoderma* at full bloom and *P. irregulare* at final harvest in 2000-2001 (Fig. 2). Roots sampled from Telone-C35 and InLine-treated plots had the highest frequency of *Pythium* spp. (values include *P. irregulare*) and roots sampled from MB plots had the lowest frequency. The *Pythium* strains were isolated from root lesions but all isolates have not been tested for pathogenicity. Colonization of roots by *Trichoderma* at full-bloom sampling was highest in InLine-treated plots, followed by iodomethane products, and the lowest levels were in MB, non-fumigated and Telone-C35 plots (Fig. 2). *P. irregulare* was isolated most frequently from roots from MB-treated plots and least frequently from InLine and other treatments were intermediate in isolation frequency at the final harvest sampling time. The frequency of isolations of fungi and stramenopiles was lower overall in 2001-2002 compared to the previous year's trial (Table 2). Plant growth parameters (average values highlighted in Table 2) were impacted in 2000-2001 only at full-bloom. Treatments had little impact on pathogen isolation frequency and plant growth parameters in 2001-2002 (Table 2).

VIDALIA, GA:
In Vidalia, GA, 2000-2001 treatments included combinations of: 1,3 dichloropropene, chloropicrin and metam sodium in conjunction with *Bacillus subtilis*, or the herbicide Devrinol®. The most promising combinations of the leading alternative chemicals were studied in 2001-2002. The eight treatments evaluated in 2001-2002 included: **1.** non-fumigated control, **2.** methyl bromide:chloropicrin 67:33 (350 lbs/treated A), **3.** InLine (35 gal/A, 2 drip tubes) + metam sodium (75 gal/A, 2 drip tubes), **4.** Telone-C35 (35 gal/A) + metam sodium (37.5 gal/A, 4 shanks), **5.** T-C35 (35 gal/A) + metam sodium (75 gal/A, 4 shanks), **6.**T-C35 (35 gal/A) + chloropicrin (130 lbs/A), **7.** InLine (35 gal/A, 2 drip tubes), **8.**T-C35 (35 gal/A). At this test site, root disease severity, foliar dry

weights, root dry weights, plant survival and yield were evaluated. In 2000-2001, all products and combinations had more total yield than the non-fumigated control and, in summary, combinations of InLine or T-C35 plus metam sodium or chloropicrin generated similar yields as compared to MB (Brannen and Louws 2002). In 2001-2002, yields collected from InLine only plots were similar to those from non-fumigated control plots and all other treatments resulted in superior yields comparable to MB-treated plots (Brannen et al. 2003).

Strawberry plants were sampled for pathogen assay only from non-fumigated control plots to understand which pathogens play important roles in BRR in the absence of chemical fumigants. Plants were sampled at full-bloom, peak fruiting and final harvest in 2000-2001 and pre-plant (bare-root), full-bloom, and final harvest in 2001-2002 (Table 3). In 2000-2001 the predominant organisms isolated from root lesions were: *Fusarium* spp., *Pythium* spp., *P. irregulare*, *R. fragariae*, and *Alternaria* spp. In 2001-2002, *Fusarium* spp. and *R. fragariae* were the most common organisms associated with root lesions.

SUMMARY: Telone C-35, metam sodium, chloropicrin and iodomethane-based formulations, or selected combinations of these products, consistently generated marketable yields of strawberries similar to those obtained with MB in regional trials (results previously reported). These products offer viable approaches to manage soilborne pathogens of strawberries if methyl bromide cannot be used. InLine performed well in 2000-2001 but not in 2001-2002, suggesting a formulation or application issue.

The dynamics of root associated fungi and stramenopiles is dynamic and complex. The frequency of isolation and types of organisms varies depending on plant source, planting site, year of isolation and timing within a growing season. Characterization of these organisms provides a basis to better understand their dynamics and to devise specific management programs. Isolation data from all three sites, Plymouth, Clayton and Vidalia, allows us to examine differences attributable to factors aside from pre-plant soil treatments. In Vidalia in 2000-2001 and 2001-2002, levels of colonization by *Fusarium* spp. were greater than levels found in both years in the Clayton and Plymouth studies. *Rhizoctonia fragariae* was not isolated from roots in Clayton, infrequently in Plymouth and at relatively high levels (dependent on timing during season) in Vidalia. *Phytophthora* spp., most notably *P. cactorum*, were not isolated at Clayton, and occurred infrequently at both Plymouth and Vidalia. Pre-plant isolations from root lesions provides a better understanding of the complex of organisms that may be introduced into fields on plants and emphasizes the need to develop systems that endeavor to minimize risk of introducing pathogens into fruiting fields.

Table 1. Mean frequency (of n strawberry root lesions plated) of isolations of listed fungi or stramenopiles from all plots sampled at Plymouth NC in 2000-01 and 2001-02. Roots were surface disinfested prior to plating on AWA and PARP. Highlighted cells indicate isolation frequencies or plant growth parameters that differ by pre-plant soil treatment.

Isolate Genus	**Plymouth 2000-2001 (n lesions =180)**		**Plymouth 2001-2002 (n lesions = 180)**		
	Full-bloom	Final harvest	Pre-plant	Full-bloom	Final harvest
Fusarium	20.0	2.2	5.0	16.3	31.1
Pythium	29.4	31.7	0.0	0.0	0.0
Phytophthora	22.2	0.0	0.0	0.7	6.7
Rhizoctonia	7.2	10.0	0.0	3.0	0.0
Phoma	0.6	0.0	0.0	3.7	2.8
Colletotrichum acutatum	0.6	0.0	0.0	0.7	0.0
Gnomonia	1.1	0.0	0.0	0.0	0.0
Cylindrocarpon	1.1	0.0	0.0	0.0	0.0
Alternaria	4.4	5.6	28.3	14.1	3.9
Trichoderma	15.6	34.4	37.2	8.1	12.8
Root health parameters					
Root health	9.8	6.2	7.9	7.9	6.1
Root rot	5.2	39.9	9.7	24.4	34.6
Root dry weight (g/plant)	4.2	3.6	…….	22.7	8.7

Table 2. Mean frequency (of n strawberry root lesions plated) of isolations of listed fungi or stramenopiles from all plots sampled at Clayton NC in 2000-01 and 2001-02. Roots were surface disinfested prior to plating on AWA and PARP. Highlighted cells indicate isolation frequencies or plant growth parameters that differ by pre-plant soil treatment.

Isolate Genus	**Clayton 2000-2001 (n lesions =120)**			**Clayton 2001-2002 (n lesions = 96)**		
	Full-bloom	Peak fruiting	Final harvest	Pre-plant	Full-bloom	Peak fruiting
Fusarium	2.5	……..	5.0	6.7	5.2	……..
Pythium	79.2	……..	52.5	0.0	0.0	……..
P. irregulare	78.3	……..	51.7	0.0	0.0	……..
Trichoderma	48.3	……..	62.5	67.5	31.3	……..
Alternaria	0.0	……..	0.0	6.9	6.3	……..
No growth of fungi	52.5	……..	42.5	55.8	93.8	……..
Plant growth parameters						
Leaf area (cm^3/plant)	2039.8	3680.2	……..	……..	1765.0	2419. 5
Root dry weight (g/plant)	5.2	7.8	3.7	……..	4.8	3.5
Crown dry weight (g/plant)	3.8	……..	4.3	……..	5.3	6.1
Root health	8.3	5.9	7.1	7.8	5.9	7.5
Root rot	25.0	32.5	22.9	4.8	8.5	10.2

Table 3. Mean frequency (of n strawberry root lesions plated) of isolations of listed fungi or stramenopiles from non-fumigated control plots from Vidalia GA in 2000-01 and 2001-02. Roots were surface disinfested prior to plating lesions symptomatic of Black Root Rot on AWA and PARP.

Isolate Genus	**Vidalia 2000-2001 (n lesions = 60)**			**Vidalia 2001-2002 (n lesions = 48)**		
	Full-bloom	Peak fruiting	Final harvest	Pre-plant	Full-bloom	Final harvest
Fusarium	62.5	50.0	53.3	12.0	45.8	47.9
Pythium	70.8	58.3	18.3	0.0	0.0	0.0
P. irregulare	25.0	37.5	5.0	0.0	0.0	0.0
Phytophthora	0.0	0.0	0.0	6.0	0.0	0.0
Rhizoctonia	0.0	54.2	1.7	8.0	100	35.4
Phoma	0.0	0.0	0.0	0.0	12.5	0.0
Alternaria	0.0	20.8	26.7	14.0	25.0	4.2
Trichoderma	8.3	4.2	5.0	14.0	8.3	2.1
Root health parameters						
Root health				4.6	7.7	5.8
Root rot (2000-01 rated on 0-5 severity scale), 2001-02 0-100 % severity scale	3.4		3.9	23.5	32.5	85.8

Figure1: Plymouth 2000-01 Strawberry Trial

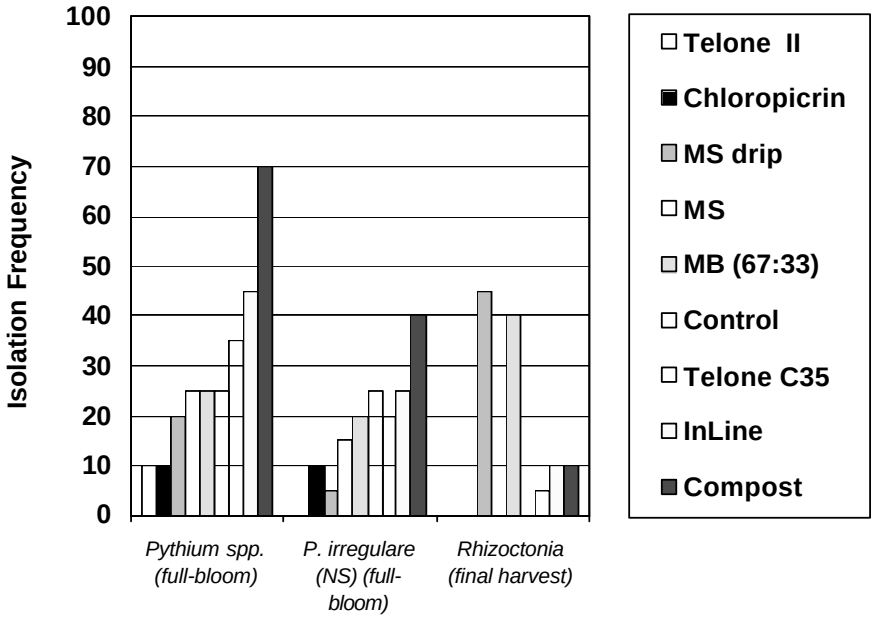
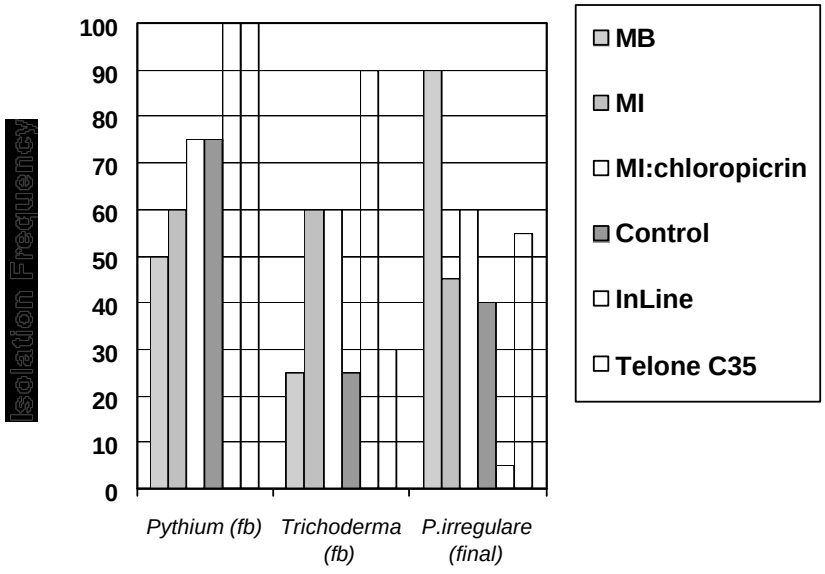


Figure 2: Clayton 2000-01 Strawberry Trial



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