

Pre-Plant Crop Rotation and Compost Amendments for Improving Establishment of Red Raspberry

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Abstract

Three crop rotation treatments: (1) a sorghum x sudangrass hybrid (Sudex) and rapeseed, (2) a conventional corn-barley rotation, and (3) a corn-barley rotation followed by preplant compost amendment, were compared for alleviating replant problems on a field with a long history of perennial fruit crops. A raspberry selection trial was planted in each treatment, and initial raspberry survival and growth over two seasons was measured to compare the efficacy of these pre-plant treatments. The initial survival and growth of raspberry plants in the Sudex-rapeseed treatment was similar to that of the corn-barley treatment. However, the corn-barley-compost treatment significantly improved raspberry growth and survival. At the conclusion of the experiment, root samples from two raspberry cultivars were assayed for root-disease associated fungi. Isolates of fast-growing fungi (*Cylindrocarpon*, *Fusarium*, *Pythium*, and *Rhizoctonia*) were found at low frequencies, but there were no significant differences in their occurrence among pre-plant treatments.

Introduction

Old orchard sites and perennial small-fruit plantings often harbor a variety of soil-borne pathogenic fungi and harmful nematode species. These organisms build up over a number of years and can inhibit the establishment of new plantings (16). Soil treatment with chemical fumigants like methyl bromide has typically been recommended to decrease the populations of undesirable soil microorganisms and thereby alleviate these replant problems. However, methyl bromide use is currently being phased out, and chemical alternatives such as metam sodium and 1,3-dichloropropene (Telone, Dow) are expensive and of limited effectiveness (10). In addition, chemical fumigants can only be used under specific conditions, limited by soil temperature, moisture, and texture,

and have limited effectiveness on rocky orchard sites (20).

Leaving the field fallow is not an effective remedy for replant problems, as weed control requires frequent cultivation. If broadleaf weeds are allowed to grow, the site will continue to harbor nematodes and nematode-vectored tomato-ringspot virus (5, 16). Legume crops also harbor nematodes and viruses. In addition to high populations of nematodes and pathogens, old orchard sites may have problems with soil compaction, internal drainage, residual herbicide activity, and soil pH (20).

Some cover crops may reduce the populations of soil-borne pathogens either through direct toxic activity or indirectly through resistance and incompatibility with root pathogens. Cruciferous plants such as *Brassica napus* L. and *B.*

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campestris L. contain glucosinolate compounds. When the plant tissue is macerated, these compounds are hydrolyzed to form isothiocyanates and related volatiles (1) that act as fumigants effective against weeds (23), fungal pathogens *Pythium ultimum* Trow. and *Rhizoctonia solani* Kuhn (*Thanatephorus cucumeris* [FR] Donk) (2), and nematodes (5, 8). The sorghum-sudangrass hybrid Sudex (*Sorghum bicolor* L. Moench x *S. 'bicolor' var sudanese*; DeKalb Seed Co.) is a rapid growing warm season annual that produces large amounts of biomass on depleted soils, and aerates compacted subsoil by producing a vigorous root system (21). The general resistance of sorghum-sudan hybrids to nematodes and diseases also helps prevent the build up of large populations of these organisms (9, 21).

The addition of organic amendments may be another alternative for reducing replant problems (7, 11). Compost as a constituent of greenhouse potting soil effectively suppresses a number of soil-borne pathogens and pests (6) to the extent that composts have replaced methyl bromide in the nursery industry (17). These beneficial effects may be partially explained by stimulated growth of beneficial organisms that help suppress root pathogens by a variety of mechanisms including competition, direct feeding, antibiosis (7, 14), and systemic acquired resistance (24). Compost amendments may also suppress a number of nematode species including *Pratylenchus penetrans* (Cobb) Filipjev & Schuurman-Steckhoven (13), a species commonly associated with replant disorders. In addition to work in potted-plant production, the efficacy of compost for control of soil-borne pathogens has been demonstrated in flax (*Linum usitatissimum* L.) and various vegetable crops (12, 18, 19).

In the present study, we compared a Sudex-rapeseed rotation, a conventional corn-barley rotation, and a corn-barley rotation with a commercial chicken manure-crab shell compost amendment as pre-plant treatments for improving the establishment of red raspberries.

Materials and Methods

A 0.25ha field at the University of Maryland's Wye Research and Extension Center, Wye Mills, Md. was selected based on a long history of small fruit and orchard plantings. The soil type is a Matapeake silt loam (mesic typic hapludult). The field was used for strawberry breeding and selection trials for 15 years, followed by nine years as a stone fruit orchard that was removed in 1995. Barley was grown for two seasons prior to this study.

In early 1998, the site was divided into nine plots 7.3 m by 30 m, that were then assigned to three blocks with each of three treatments assigned within each block. The treatments consisted of a Sudex-rapeseed rotation, a corn-barley rotation, and a corn-barley rotation followed by pre-plant amendment with a commercial chicken manure-crab shell compost (Table 1). In April of 1998, a winter cover crop of crimson clover growing on all plots was plowed down, followed by the application and incorporation of a 16-8-8 fertilizer (72 kg N • ha⁻¹) and dolomitic lime (2.24 t • ha⁻¹).

Sudex-rapeseed treatment. On 28 April 1998, plots assigned to the first treatment were seeded to Sudex (Dekalb SXB) at a seeding rate of 30 kg • ha⁻¹. On 7 July, the Sudex was mowed and ammonium sulfate fertilizer was applied at 18 kg N • ha⁻¹. On 12 August, the Sudex plots were again mowed, disced (13 August), and plowed (20 August), and an additional 2.24 t • ha⁻¹ lime was applied. On 8 September, rapeseed (*Brassica napus* 'Dwarf Essex', Wetzel Seeds, Harrisonburg, Va.) was planted at a seeding rate of 11.2 kg • ha⁻¹. On 19 April 1999, the rapeseed was mowed and immediately incorporated by plowing to a depth of 20 cm. Three weeks after incorporating the winter rapeseed crop (12 May), a second crop of rapeseed was seeded at the same rate. On 20 August, the second rapeseed crop was mowed, and immediately disced and plowed into the top 20 cm of soil.

Corn-barley treatment. Plots assigned to the corn-barley and corn-barley compost

Table 1. Timeline for three pre-plant treatments, listing fertilization, cultivation and seed inputs.

Date	Treatment		
	Sudex-rapeseed	Corn-barley	Corn-barley-compost
Apr-98	16-8-8 fertilizer (72 kg N/ha) lime (2.24 t/ha) plant sudex	16-8-8 fertilizer (72 kg N/ha) lime (2.24 t/ha) plant sweet corn banded 16-8-8 fertilizer (36 kg N/ha) herbicide	16-8-8 fertilizer (72 kg N/ha) lime (2.24 t/ha) plant sweet corn banded 16-8-8 fertilizer (36 kg N/ha) herbicide
May-98	—	side-dress 33.6 kg N/ha	side-dress 33.6 kg N/ha
July-98	mow sudex	—	—
Aug-98	mow, disc, plow	mow, disc, plow	mow, disc, plow
Sept-98	lime plant rapeseed	lime	lime
Oct-98	—	plant barley NH ₄ SO ₄ , 8.3 kg N/ha	plant barley NH ₄ SO ₄ , 8.3 kg N/ha
Apr-99	Mow rapeseed plow	— plow	— plow
May-99	fertilize, 18 kg N/ha plant rapeseed	fertilize, 18 kg N/ha plant sweet corn band 10-10-10 (22.4 kg N/ha) herbicide	fertilize, 18 kg N/ha plant sweet corn band 10-10-10 (22.4 kg N/ha) herbicide
Aug-99	mow, disc, plow	mow, disc, plow	mow, disc, plow
Sept-99	lime	lime	lime
Apr-00 to May-00	Strip spray glyphosate and gramoxone	Strip spray glyphosate and gramoxone	Strip spray glyphosate and gramoxone apply compost

treatments were seeded to sweet corn on 30 April 1998, and received a banded application of 16-8-8 fertilizer at 36 kg N • ha⁻¹. The herbicides atrazine (1.12 kg • ha⁻¹ AAtrex, Novartis) and cyanazine (2.47 kg • ha⁻¹ Bladex, DuPont Agric.) were applied at planting time. One month later (29 May), the corn plots received a side-dress application of ammonium nitrate, at 33.6 kg N • ha⁻¹. The corn was mowed on 3 August and the crop residue was incorporated by discing and plowing in late August, followed by the application of lime at 2.24 t • ha⁻¹. On 15 October 1998, plots were seeded with barley at a seeding rate of 80 kg • ha⁻¹, and fertilized with ammonium sulfate at 27.6 kg N • ha⁻¹. The barley crop was plowed under on 19 April 1999, after which ammonium sulfate was applied at 8.3 kg N • ha⁻¹ (27 Apr). Sweet corn was

planted on 7 May, with a 10-10-10 fertilizer side dress at 22.4 kg N • ha⁻¹, and herbicide application of atrazine (1.12 kg • ha⁻¹ AAtrex, Novartis) and metolachlor (1.17 L • ha⁻¹ Dual, Novartis). The corn was mowed on 16 August, then disced and plowed (20 August).

Plots for all three treatments received 2.24 kg • ha⁻¹ lime on 1 September 1999 and were then seeded to endophyte-innoculated tall fescue (*Festuca arundinacea* Schreb. 'Kentucky 31') at a rate of 135 kg • ha⁻¹.

In the spring of 2000, two rows 3.05 m apart and 24 m long were marked in each plot. For each row a 1.2m wide strip was treated with glyphosate (31 March) followed by gramoxone (13 Apr). For the compost treatment, a chicken manure-crab shell compost obtained from a commercial

composting facility (New Earth Services, Cambridge, Md.) was spread over the herbicide strip, at a depth of 7.5 cm, and incorporated to a depth of 18 cm with a rotary tiller.

Raspberry establishment. The two rows in each plot were divided into five 3m sub-plots with 1.8m buffers between sub-plots. One row in each plot was assigned floricanefruiting, and the other primocanefruiting selections. The five selections were randomly assigned within their respective rows, and planted at 0.6-m spacing within the assigned plot. The five floricanefruiting selections were 'Royalty' and 'Emily' (tested as JAM-1), and three advanced selections, PBL-B1, PCA-B4, and PCS-1, from the Maryland-New Jersey-Virginia-Wisconsin (MNVW) cooperative small fruit breeding program. The unnamed lines were selected under high *Phytophthora* disease pressure. The five primocanefruiting genotypes were 'Autumn Britten', 'Caroline', and the MNVW selections 'Deborah' (ND-f1), 'Alice' (OAY-f1), and QQ-f1. Plants of 'Autumn Britten', 'Royalty', and 'Caroline' were obtained as dormant bare-root canes from a commercial nursery (Nourse Farms, South Deerfield, Mass.). For the remaining selections, plug plants in 50-cell trays were provided by the breeder. Dormant bare-root canes were planted in propagation flats containing a commercial potting soil, and grown in the greenhouse for one month before transplanting to the field. On 12 May 2000, plug plants were planted using a mechanical vegetable transplanter, and the rooted canes were planted by hand. Dead plants were replaced with additional nursery plants in June 2000, and again in April 2001.

Culture and management. The new raspberry planting was initially established under overhead irrigation. A trickle irrigation system was later installed and used throughout the rest of the experiment. One month after planting, calcium nitrate fertilizer was applied at a rate of 33.3 kg N • ha⁻¹, and split applications of 33.6 kg N • ha⁻¹ fertilizer

were applied in May and June of 2001. Weed control was by directed herbicide application, and limited hand weeding during the establishment year.

Data collection and analysis. Plant establishment and vigor were quantified by determining mortality in the fall of 2000, and by measuring mid-winter above-ground biomass after each of the first two growing seasons. For determining above-ground biomass in the less vigorous treatments, the entire 3-m sub-plots were sampled by cutting canes back to within 15 cm of the soil surface with the total number and weight of removed canes recorded. In the most vigorous sub-plots, 1-meter-long sections were randomly selected, and data collected for these. After the first season, the remainder of the sub-plots were also pruned back, but data were not collected. At the end of the second season, the remaining plots were left to grow for later disease sampling and vigor ratings.

At the termination of the experiment in April 2002, plots were rated for vigor, and individual plants were sampled for disease. For disease sampling, two plants from each plot of 'Royalty' and 'Caroline' were selected randomly, and leaves removed for virus testing. Leaf samples were assayed for tomato ringspot virus using a commercial assay kit (Agdia, Elkhart, Ind.). Roots of the selected plants were excavated, washed, and assayed for soil-borne pathogenic fungi according to the following procedure. Ten 5-mm segments of viable looking roots were aseptically excised from each raspberry plant after the roots had been surface sterilized and blotted dry. Root segments were plated on water agar containing antibiotics (100 ug/ml vancomycin and 10 ug/ml rifampicin) and incubated at 22° C in the dark. As fungal hyphae began to grow out of roots and into the agar, hyphal tips from individual colonies were transferred to fresh plates of one-half strength potato dextrose agar with antibiotics for identification. Techniques were not optimized for the isolation of *Phytophthora spp.*, very slow growing fungi, but have been effective.

tive at capturing faster growing prevalent root-associated fungi present in the samples (Millner, unpublished data). During the first week of incubation, all individual colonies were sub-cultured for identification. Occasionally, only 2-3 isolations could be made from a single plant because of the presence of very fast growing hyphae. Colonies of pathogenic genera were identified by colony and microscopic morphology by comparison to reference strains. Frequency of pathogenic genera were quantified as the number of occurrences in 20 root samples assayed for each replicate.

The results were analyzed as a split-plot design with blocking, where the whole plot factor was pre-plant treatment, and the subplot factor was raspberry genotype. Analysis of variance was carried out using the GLM procedure of the SAS program, with treatment means compared using the PDIF option of the LSMEANS statement.

Results

Initial survival and early growth of raspberry plants differed significantly among genotypes and among treatments, but there were no significant genotype x treatment interactions (Table 2). Growth and survival after the first season was not significantly different between the Sudex-rape-seed and the corn-barley treatments (Table 2). After the second growing season, raspberry growth in the Sudex-rape-seed treatment tended to be greater than that of the corn-barley treatment, but differences were not statistically significant. However, vigor ratings were significantly higher for the Sudex-rape-seed treatment than for the corn-barley control (Table 2). Average cane weight after both seasons differed significantly among genotypes, but not among pre-plant treatments.

There were four general genotype responses. 'Royalty', 'Caroline' and the selection PBL-B1 established quickly and maintained relatively good growth, as indicated by 2001-2002 biomass data. PCS-1, 'Alice' and QQ-f1 had a higher biomass in the second year, indicating general tol-

erence of the conditions at the site. PCA-B4 did not tolerate planting, but an increased amount of growth in the second year indicated it was adapted to the conditions of the field. 'Autumn Britten', 'Emily' and 'Deborah' produced a relatively small amount of growth after planting and declined, or remained static, in their biomass accumulation in year two. In general, the maximum amount of second year growth occurred in florican-fruited genotypes.

For all survival and growth variables, the corn-barley-compost treatment was significantly higher than the remaining treatments after both seasons. Both cane number and total biomass in the compost treatment were nearly twice that of the remaining treatments (Table 2). The final vigor rating determined for each plot was based on a 0 to 10 scale, with 10 equivalent to very vigorous stand establishment. Recorded values for vigor of individual plots ranged from 0 to 8, with treatment averages well below what would be considered commercially acceptable (Table 2).

Commercial assay kits indicated no detectable levels of tomato ringspot virus in any of the plants sampled. Isolates of the genera: *Cylindrocarpon*, *Fusarium*, *Pythium*, and *Rhizoctonia* were found in samples from all treatments, at average frequencies ranging from <1 to 11.3 per 20 samples (Table 3). There were no significant differences in frequency of occurrence among pre-plant treatments. Of the four genera, *Cylindrocarpon* was most frequently isolated, and *Rhizoctonia* was least frequently isolated. *Trichoderma* and *Penicillium* were also found at low frequencies among all treatments (data not shown).

Discussion

Replant disorders can be attributed to one or a combination of factors including: large populations of pests or pathogens, poor soil conditions, and herbicide residues. We found that pre-plant compost amendment improved raspberry establishment on a site with a long history of perennial fruit crops. A number of studies in nursery and vegetable crops have shown

Table 2. Initial survival and growth during the first two seasons of raspberry genotypes planted in three pre-plant treatments. Cane number and biomass were determined from samples collected prior to spring bud break, and are expressed as a function of row length. With no significant treatment x genotype interactions, only means comparisons for pre-plant treatment are shown.

Genotype	Fall 2000	Winter 2000-2001		Winter 2001-2002		Spring 2002
	Survival (%)	Cane count (canes/m)	Biomass (g/m)	Cane count (canes/m)	Biomass (g/m)	Final vigor ²
<i>Floricanne fruiting</i>						
'Emily'	60.0	3.8	48	4.6	49	2.0
'Royalty'	91.1	7.7	189	15.9	299	6.1
PBL-B1	91.1	14.1	172	15.7	218	3.9
PCA-B4	37.8	1.8	18	6.6	67	2.7
PCS-1	68.9	8.3	73	15.1	219	3.6
<i>Primocane fruiting</i>						
'Autumn Britten'	37.8	7.1	56	4.9	32	2.8
'Caroline'	55.6	18.7	158	18.6	126	3.8
'Deborah'	88.9	4.8	70	9.4	46	3.8
'Alice'	68.9	6.7	84	12.9	141	3.4
QQ-F1	80.0	6.6	74	15.1	131	3.0
Treatment						
Sudex-rapeseed	64.0 a ^y	5.1 a	52 a	8.5 a	91 a	3.6 b
Corn-barley	64.7 a	5.9 a	78 a	8.0 a	81 a	2.4 a
Corn-barley-compost	75.3 b	12.9 b	152 b	19.1 b	227 b	4.5 c
ANOVA						
Treatment	0.0098	0.0017	0.0048	0.0012	0.0355	0.0083
Clone	0.0001	0.0002	0.0295	0.0137	0.0002	0.0001
Tmt *clone	0.8479	0.3378	0.9740	0.5529	0.4523	0.2444

²Final vigor was rated on a scale of 1-10, with 10 indicating a very vigorous stand. Recorded values for individual plots ranged from 0 to 8.

^yTreatment mean comparisons were determined by the PDIF option of the GLM procedure of SAS. Means in the same column followed by different letters are significantly different at $P < 0.05$.

Table 3. Frequency of isolation of select fungi from the roots of 'Royalty' and 'Caroline' raspberry. Cumulative frequency (total) of *Pythium*, *Cylindrocarpon*, *Rhizoctonia*, and *Fusarium* are shown in column 6.

Treatment	<i>Pythium</i>	<i>Cylindrocarpon</i>	<i>Phizoctonia</i>	<i>Fusarium</i>	Total
'Royalty'					
Sudex-rapeseed	1.7±0.9 ²	4.3±1.7	<1	2.0±0.6	8.3±1.2
Corn-barley	1.3±0.3	3.0±1.0	<1	1.7±0.3	6.3±1.4
Corn-barley-compost	2.0±1.2	3.0±0.6	<1	1.3±0.9	6.7±1.8
'Caroline'					
Sudex-rapeseed	1.7±0.9	3.3±2.0	<1	1.7±0.3	7.3±2.3
Corn-barley	3.3±0.7	3.0±1.5	1.3±1.3	3.7±3.7	11.3±3.9
Corn-barley-compost	2.7±0.7	3.3±0.9	<1	<1	6.0±0.6

²Values are the number of isolations in 20 root samples assayed, with mean ± standard error for the three replicate plots.

the potential of compost application for suppressing soil-borne pathogen populations (for reviews see 6, 7). However, we did not find differences in root colonization by *Cylindrocarpon*, *Fusarium*, *Pythium* and *Rhizoctonia*. In a parallel study at a separate location, we did note some plant death with symptoms similar to that of *Phytophthora* root rot, which can be a major disease problem of raspberry associated with replant disorders, particularly in wet soils (16). However, the protocol used here was not selective enough for detection of *Phytophthora fragariae* and other slow-growing root-associated fungi.

The effects of composts on pathogen populations can be inconsistent. Some have reported beneficial effects of one compost and detrimental effects of another compost within the same experiment (4, 22, Brian Smith - personal communication). These inconsistencies may be due to differences in source material, microbe recolonization, or compost maturity (7, Miller - unpublished data). However, compost amendment may also alleviate replant disorder by reducing residual herbicide activity. Raspberries are particularly sensitive to herbicide residues from previous crops (16), and herbicides are known to complex with organic matter (15).

The differences between the compost treatment and the other treatments may have been due to improved soil physical properties. Raspberry plants are shallow rooted and have low tolerance for wet soils (16). Compost amendment improves soil aeration by increasing aggregate stability and porosity of silt and clay soils (3). The differences in plant vigor could have resulted from such an improvement in soil physical properties. In addition to the compost amendment, improved soil properties also could have resulted from the additional cover crop inherent in the experimental protocol. In the Sudex-rapeseed, and corn-barley treatments, the raspberry plants were planted directly into a killed fescue sod. However, the killed sod was turned under during the incorporation of the compost, so that plants in this treatment were placed in freshly-tilled soil.

The compost treatment received the most nitrogen over the course of the experiment, but there were no signs of N deficiency in any of the treatments and leaf N analysis during the first season did not indicate deficiency (data not shown). Further, growth and vigor differences were likely not the result of differences in pre-plant N, as the corn-barley control received more N than the Sudex-rapeseed treatment but showed less growth and vigor over the course of the experiment.

Another factor determining success of planting on heavier soils, is genotype selection. Large genotype differences in growth were noted in this experiment. 'Royalty', with black raspberry in its pedigree, is known to be resistant to *Phytophthora* root rot, but is susceptible to tomato ringspot virus. It established well and continued to increase its biomass accumulation in year two. If plants had become infected with tomato ringspot virus the rate of biomass accumulation would have decreased over the course of the experiment (Stiles, unpublished). Of the remaining genotypes, three (PBL-B1, PCA-B4, PCS-1) were selected in fields known to be infested with *Phytophthora* and prone to experiencing a high water table. All three were adapted to the conditions of the field although PCA-B4 had losses in establishment. Five of the remaining cultivars were selected on sandier soil; of these, two ('Alice' and QQ-f1) had greater growth in the second year, and three ('Caroline', 'Deborah' and 'Emily') had second-year growth that was less than the first year. 'Caroline' continued to produce a larger amount of biomass than one of the genotypes selected under root rot conditions (PCA-B4). Evidently, high selection pressure at the seedling stage translated into adaptability to wetter soils.

Although crop residues of both sorghum-sudan grass hybrids and *Brassica* species such as rapeseed have shown effects in alleviating replant problems in other systems, the combination of these crops did not show dramatic effects in this experiment. It should be noted that the site used for this study was planted to barley

for two years prior to the start of this experiment. Therefore the corn-barley control effectively resulted in four years of agronomic crop rotation between perennial fruit crop plantings. This may have decreased soil-borne pathogen and pest populations sufficiently to alleviate potential replant disorders. Perhaps the best treatment would be a combination of Sudex-rapeseed rotation, compost amendment, and adapted genotypes. Clearly, the scheduled phase-out of methyl bromide necessitates new approaches to alleviate replant disorders in establishment of perennial crops, and our results indicate that compost amendment may be a promising alternative.

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