Evaluating Dominus® Soil Biofumigant as a Substitute for Methyl Bromide in Pacific Northwest Forest Nurseries

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Abstract

Dominus® is a new soil biofumigant that is registered for use in bareroot forest nurseries with minimal buffer zone requirements. The active ingredient is allyl isothiocyanate (AITC), a compound found in certain mustard family plants (Brassicaceae). Washington Department of Natural Resources Webster Nursery (Tumwater, WA) tested five treatments applied in September 2015: (1) Dominus® alone; (2) Dominus® plus chloropicrin; (3) chloropicrin alone; (4) an operational control of methyl bromide plus chloropicrin; and (5) a nontreated control. All treatments were immediately tarped with totally impermeable film (TIF). In May 2016, Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) seedlings were transplanted into the treatment plots. Height and stem diameter differences throughout the trial were minimal and nonsignificant among treatments. Dominus®, with or without chloropicrin, significantly lowered soil *Fusarium* populations one month after treatment to levels similar to the standard methyl bromide plus chloropicrin fumigation. All fumigation treatments maintained lower soil and root *Fusarium* populations than the nontreated control through the trial. Dominus® reduced initial (winter) weed presence similarly to the operational standard, but low weed pressure during the growing season limited meaningful evaluation of the fumigant treatments' herbicidal effects. This paper was presented at the joint annual meeting of the Western Forest and Conservation Nursery Association and the Intermountain Container Seedling Growers' Association (Troutdale, OR, September 14–15, 2016).

Introduction

The standard practice in the Pacific Northwest (PNW) forest nursery industry to address soilborne insects, weeds, and pathogens is to fumigate with a mixture of methyl bromide plus chloropicrin. Recent changes to fumigant application regulations and pesticide labels, however, have significantly limited the use of methyl bromide and other fumigants in forest nurseries (EPA 2017, Enebak 2007, Masters 2005). Buffer zone requirements have increased fumigation costs, and, in some cases, restricted the use of fumigation entirely in increasingly suburban situations (Weiland et al. 2013). Many nurseries, to reduce buffer-zone limits, pay an extra expense for the contract fumigator to split applications to the same field on different dates.

Methyl bromide alternatives in the PNW have been examined for decades (Littke et al. 2002, Hansen et al. 1990). Chemical alternatives such as dimethyl disulfide or methyl iodide, both in combination with chloropicrin, have compared favorably to methyl bromide fumigation at nurseries in the PNW, but neither is currently registered due to environmental concerns. Methyl isothiocyanate (MITC)-producing agents (dazomet and metam sodium) have also been studied. Although dazomet, a granular product, can be inconsistent in conversion and performance, metam sodium, a liquid, in combination with chloropicrin, performed similarly to methyl bromide in a recent study (Weiland et al. 2011).

Brassica (Mustard) Biofumigation as an Alternative to Methyl Bromide

One line of research in alternatives to methyl bromide studies has examined the use of Brassica spp. (Brassicaceae; mustard family) cover crops; Brassica is crushed and immediately incorporated in to soil as a biofumigant, to reduce pathogen pressure. Glucosinolates in these crops hydrolyze in the presence of the enzyme myrosinase into AITC, a compound with pesticidal properties (Mazzola et al. 2007). AITC shares some similarities to the active ingredient MITC mentioned previously.

In studies at the U.S. Department of Agriculture, Forest Service's nursery in Coeur d'Alene, ID, and Weyerhaeuser Company's Washington and Oregon nurseries in the late 1990s and early 2000s, Brassica cover-crop biofumigation in Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) bareroot seedling beds failed to adequately control pathogen and weed populations, and in many cases, exacerbated soil pathogen levels post-fumigation (Hildebrand et al. 2004, Stevens 1996). Trials from 2009–2011 at Washington Department of Natural Resource's (WADNR) Webster nursery (Tumwater, WA), and the IFA Nurseries, Inc. Toledo nursery (Toledo, WA), in cooperation with Washington State University (Pullman, WA), examined the latest brassica cultivars bred for high glucosinolate (AITC precursor) cover crops as well as seed meals with relatively high glucosinolate content. Incorporated brassica material was immediately tarped with HDPE (high-density polyethylene) in an attempt to maximize treatment effect. Again, these trials produced inconsistent results in Douglas-fir transplant beds, with occasional exacerbation of pathogen levels and failure to produce effective weed control (Paudel et al. 2016). James et al. (2004) explained similar results by theorizing that insufficient toxicity levels in combination with increased organic matter can result in an unintended favorable environment for pathogens.

A challenge for both cover crop and seed meal applications of biofumigation is quantity. In the case of cover-crop application, as much as 22 tons/ac (50 metric tons/ha) has been estimated for adequate disease control (Clarkson et al. 2013). Seed meal applications up to 2 tons/ac (4.5 metric tons/ha), which in theory would have a more concentrated effect than green manure, have failed to consistently control soil pathogens even to the level of cover-crop incorporation (Mazzola and Gu 2002, Paudel et al. 2016). Combinations of seed-meal species mixtures appear to have more promise than single seed-meal applications, but the effects are species-dependent and pathogen-dependent (Mazzola and Brown 2010).

For brassica cover crop incorporation, Morra and Kirkegaard (2002) found that efficient isothiocyanate production from brassica is dependent on the species and variety, amount of tissue incorporated, growth stage when macerated and incorporated, thoroughness of tissue cell disruption, and climate and tillage system. One study showed that no more than 1 percent of AITC predicted from glucosinolate precursor concentrations was actually measured in soil amended with mustard leaf tissue (Kirkegaard 2009). Increases in crop performance observed in particular areas may have more to do with improving soil health parameters rather than direct pathogen reduction (Handiseni et al. 2013).

Ultimately, biofumigation through cover crop or seed meal incorporation is unlikely to be accepted by growers as a sustainable disease management alternative due to operational challenges and inconsistent results experienced to date. The best use of these biofumigation tools may be in conjunction with other integrated pest management practices in a holistic disease management approach (Bolda 2015).

Dominus®, a Concentrated Brassica-Based Biofumigant

In 2014, Isagro USA, Inc. (Morrisville, NC) received labeling in the State of Washington for the new soil biofumigant Dominus®. This product, applied through conventional nursery fumigation equipment, is a very close mimic of the naturally occurring AITC compound and is produced at 96-percent concentration active ingredient. The concentrated product increases the potential for consistent pathogen reduction, compared with incorporated cover crop or seed meal applications, due to its ability to achieve higher AITC levels in the soil.

The Environmental Protection Agency (EPA) fast tracked the registration of Dominus® under its biopesticide division (Rusnak 2013). No fumigation management plan is required, and the label requires a maximum buffer zone of 25 ft (7.6 m) from the edge of application, regardless of soil type, field size, etc. Also, the EPA did not limit the number of acres that can be treated in a day (Isagro 2016).

Fennimore (2014) evaluated Dominus® in a drip-irrigation, standard polyethylene-tarped strawberry (Fragaria x anannasa 'Monterey') row system in two trials. In the first trial, Dominus® was tested at rates of 340, 225, and 170 lb/ac (381, 252, and 191 kg/ha) against an operational standard of 350 lb/ac (392 kg/ha) PicClor60 (57:37 chloropicrin:1,3 dichloropropene) and a nontreated control. Yields were 95, 89, and 62 percent of the operational standard. In a second trial, 67:33 mixtures of Dominus®:chloropicrin were tested at 360, 270, and 180 lb/ac (404, 303, and 202 kg/ha), compared with Dominus alone at 340 lb/ac (381 kg/ha), a chloropicrin alone application of 300 lb/ac (336 kg/ha), the PicClor60 operational standard detailed previously, and a nontreated control. Across all treatments, harvest weights were highest for the 340 lb/ac (381 kg/ha) Dominus®:chloropicrin and 300 lb/ac (336 kg/ha) chloropicrin alone treatments. The medium rate of 270 lb/ac (303 kg/ha) Dominus®:chloropicrin yielded similar harvest weights to the operational standard. The Dominus® alone and all Dominus®:chloropicrin treatments outperformed the nontreated control, with the high rate of 340 lb/ac (381 kg/ha) Dominus®:chloropicrin more than doubling the control yield. In both trials, satisfactory weed control, particularly for yellow nutsedge (*Cyperus esculentus* [L.]), was only achieved at the high-end rates of 340 lb/ac (381 kg/ha) Dominus® alone or the 360 lb/ac (404 kg/ha) Dominus®:chloropicrin mixture.

Bolda (2015) found that a 360 lb/ac (404 kg/ha) Dominus®:chloropicrin 67:33 combination under a polyethylene tarp resulted in strawberry yields that were not significantly different from a 300 lb/ac (336 kg/ha) methyl bromide:chloropicrin 67:33 application.

Due to the immobile nature of AITC gas, Dominus® is best suited to lighter soil types in warm conditions to enhance its ability to move through the soil profile (Isagro 2016). Nearly all forest nurseries are located on light soils due to the need for good drainage and ease of winter lifting operations, but the requirement for warm soil temperatures to aid in gas mobility makes Dominus® a better fit for late summer fumigation, compared with spring fumigation.

Despite this limitation to warm-soil application, the early results from the strawberry industry are encouraging for Dominus application in conifer systems. Conifers share a relatively similar soil-disease complex to that found in strawberry production, particularly the prevalence of *Fusarium oxysporum* as a major pathogen (James 2004, Fennimore 2014, Bolda 2015). The objective of our study was to examine Dominus® as a potential substitute for current use of methyl bromide soil fumigation in conifer nurseries.

Materials and Methods

Nursery

Field trials were established at the WADNR Webster nursery. The soil is classified as a Cagey loamy sand (USDA NRCS 1987). The last crop of seedlings in the trial field was harvested in March 2015. In April 2015, the trial field was sown with a *Brassica juncea* (L.) Czern. 'Caliente 199' cover crop then mowed and tilled in July (one month before fumigation treatments).

Fumigation Treatments and Experimental Design

Working with Trident Agricultural Products (Woodland, WA), five fumigation treatments (table 1) were applied in early September 2015 in a randomized complete block design with four replicate blocks. All treatment plots, including the nontreated control, were immediately tarped with totally impermeable film (TIF) (Raven Industries; Sioux Falls, SD) (figure 1). Treatment plots were approximately 15 by 35 ft (5.0 by 11.5 m). TIF tarp was cut 20 days post-fumigation to enable venting and was removed the following day (22 hours post-cutting).

Thirty bed feet (approximately 700 seedlings) of 1-year-old, coastal Douglas-firs were transplanted into each treatment-replication plot in May 2016.

Sample Collection

Nursery soil was sampled five times during the experiment: on September 8, 2015 just before fumigation

Table 1. Fumigation treatments applied to bareroot nursery soil in September 2015 in a randomized complete block design with four replicate blocks.

Fumigation treatment	Rate
Nontreated control	n/a
Dominus® (AITC)	340 lb/ac (381 kg/ha)
Pic	250 lb/ac (280 kg/ha)
Dominus® (AITC) + Pic	340 lb/ac (381 kg/ha) + 125 lb/ac (140 kg/ha)
MB + Pic (operational control)	167.5 lb/ac (188 kg/ha) + 82.5 lb/ac (92 kg/ha)

AITC = allyl isothiocyanate. Pic = chloropicrin. MB = methyl bromide. N/a = no fumigant.

Figure 1. Fumigation plots were installed at Washington Department of Natural Resources Webster Nursery on September 9, 2016 to evaluate Dominus® biofumigant as an alternative to methyl bromide. (Photo by Nabil Khadduri)

(prefumigation); three weeks after fumigation on September 30, 2015 (post-fumigation); one week before planting on May 3, 2016 (preplant); on July 23, 2016 (mid-season); and February 6, 2017 (harvest). Soil samples were collected by taking twenty 1-in (2.5-cm) diameter cores in a randomized pattern to a depth of 12 in (30 cm) from each treatment plot. Samples were bulked by plot and mixed thoroughly to generate 20 composite samples. Each composite sample was then divided to provide separate samples for *Fusarium* and *Pythium* analyses. Samples were stored at 38 °F (4 °C) until assays were completed.

Douglas-fir seedlings were sampled prior to planting (preplant), in July 2016 (mid-season), and in February 2017 (harvest). Ten seedlings per time period were selected at random from within the center 10 ft (3 m) of the plot, for assays of *Fusarium* and *Pythium* root colonization. Seedlings were stored at 38 °F (4 °C) until assays were completed.

Fusarium Populations

Soil *Fusarium* colonies from soil samples were enumerated on Komada's medium (Komada 1975), and colony-forming units (CFU/g) were determined on a dry-mass basis. From each composite sample, 0.04 oz (1 g) of soil was diluted in 2.7 oz (80 ml) of 0.1 percent agar, and a 0.014 oz (0.40 ml) aliquot of the soil-water agar slurry was placed in each of the three replicate Petri plates. Prepared Komada's medium was cooled to 38 °C, poured into plates containing the slurry, and then mixed by gently stirring the plates. Plates were then placed in an incubator at 25 °C with 16 hours per day of fluorescent light for one week, at which point *Fusarium* colonies were counted using morphological traits (Leslie and Summerell 2006) (figure 2a).

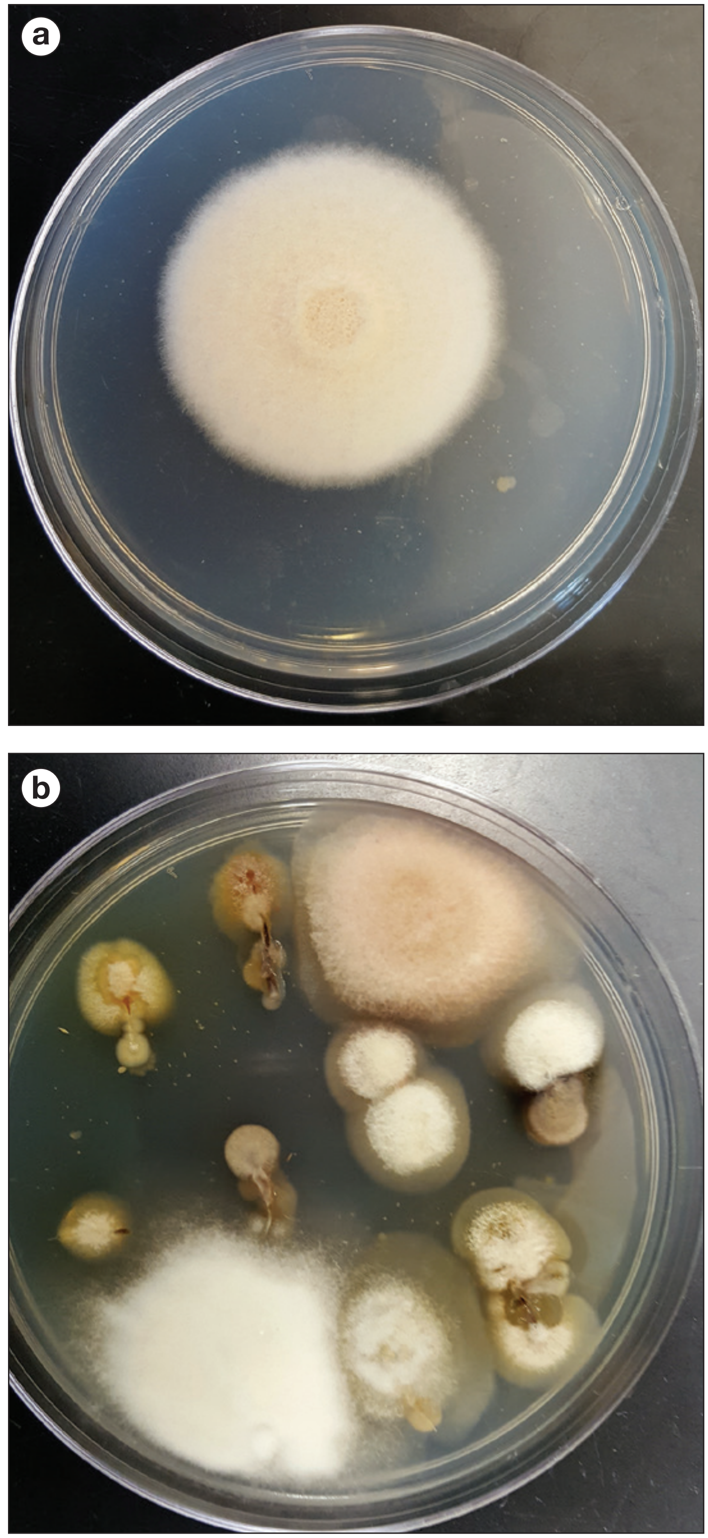

Figure 2. *Fusarium* colonies were quantified on soil and root samples. These photos show (a) a well-developed *Fusarium* colony from soil plate and (b) Fusarium infection of seedling root segments. Both photos are from July 23, 2016 sampling. (Photos by Anna Leon)

Roots of each seedling were washed free of soil, cut into ten 0.4-in (1-cm) long segments, sanitized in 10-percent bleach for 10 min, and rinsed in distilled water. Ten root segments per sample were then plated on Komada's medium and incubated as described previously (figure 2b). Following incubation, the percentage-root segments colonized by *Fusarium* in each plate for each seedling were calculated.

Pythium Populations

Pythium colonies were counted through plating Rhododendron spp. baits on clarified V8 juice-based agar (Stevens 1974) with the following post-autoclave amendments to reduce competing microbial activity: 0.15 g pentochloronitrobenzene, 0.20 g streptomycin sulfate, and 1.5 ml rose bengal. From each composite sample, 0.04 oz (1 g) of soil was diluted in 2.7 oz (80 ml) of 0.1-percent agar. Ten 0.015 oz (0.40 ml) aliquots of the soil-water agar slurry were then placed in a sterile, empty 100-mm diameter Petri plate. A sterile 8-mm round piece of rhododendron leaf was placed in each of the 10 aliquots. Rhododendron leaves were allowed to rest in the soil-water agar slurry for 48 hours before being plated onto V8 media and incubated in the dark for 48 hours. Colony morphology was checked after 24 and 48 hours. The percentage of *Pythium*-positive rhododendron disks was calculated.

Roots of each seedling were washed free of soil, cut into ten 0.4-in (1-cm) long segments, sanitized in 10-percent bleach for 10 min, and rinsed in distilled water. Ten root segments per sample were then plated on V8 media and incubated as described previously. The percentage of roots segments colonized by *Pythium* for each seedling was calculated.

Weed Evaluation

Weed sampling was conducted in November 2015 and February 2016 prior to any herbicide application and in July 2016, after seedling planting and the application of preemergent herbicides had occurred. Three 1-x-4 ft (30-x-121 cm) frames were placed at random within the inner 15 ft (5 m) of each plot. At each sampling date, weed species were identified, and total weeds were tallied. For the July 2016 evaluation, the amount of weeding time necessary was also recorded for each plot.

Seedling Morphology

Twenty-five Douglas-fir seedlings per treatment plot were measured for height and stem diameter just after planting in May 2016, in late August, and at the end of active growth in November (figure 3). At final harvest, ten seedlings per treatment plot were measured for root and shoot volume.

Statistical Analyses

All data were analyzed by sample date for treatment effects using analysis of variance, or ANOVA. Differences among treatment means were determined using a protected Fisher's least significant difference test and Tukey's Honestly Significant Difference test for multiple comparisons at $p < 0.05$. Analyses were performed using the R statistical package (R Core Team 2016).

Results

Fusarium Populations

Prefumigation (September 2015) *Fusarium* population means were similar among treatments (figure 4). Three weeks after fumigation, soil *Fusarium* populations were reduced by all treatments to low levels compared with the nontreated control plots. In May of 2016, the week before transplanting (preplant), *Fusarium* levels had declined in the nontreated control and increased in the Dominus® (AITC) alone treatment, although the Dominus®-treated soils still averaged one-half the *Fusarium* level of the nontreated control soils. All other treatments remained significantly lower than the nontreated control (figure 4). By mid-July 2016, all soil *Fusarium* levels were low, with no significant differences among treatments. At harvest in February 2017, soil *Fusarium* levels had risen in the control plots and were again significantly higher than all other treatments (figure 4).

Seedling root infection at preplant was low across all treatments (figure 5). By late July, seedlings in the nontreated control plots had significantly higher levels of *Fusarium* root disease than all fumigation treatments. This pattern maintained through sampling at harvest (figure 5).

Figure 3. Seedling plots at Washington Department of Natural Resources Webster Nursery to evaluate fumigation treatments: (a) May 2016 at transplanting; (b) August 2016; and (c) February 2017 at harvest. (Photos by Nabil Khadduri)

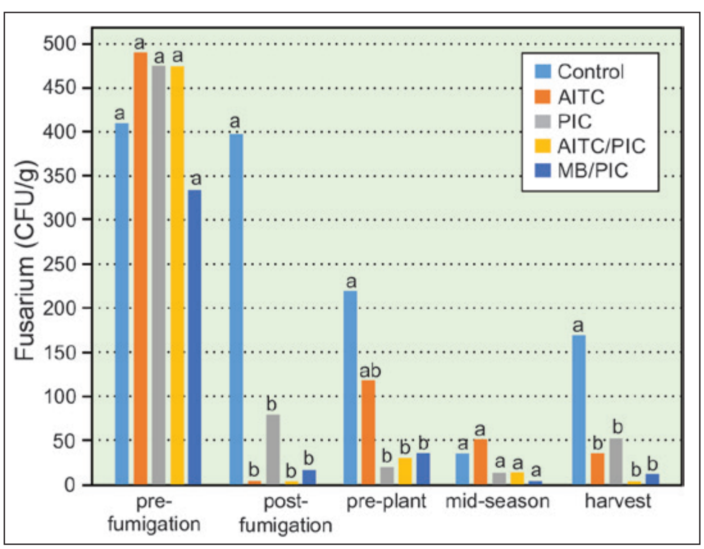

Figure 4. Soil *Fusarium* population means were similar among treatments prior to fumigation. Three weeks after fumigation (September 30, 2015), soil *Fusarium* populations had declined significantly in all fumigation treatments compared with the nontreated control plots. Although soil *Fusarium* levels in nontreated control plots declined to nonsignificant levels by mid-season (July 23, 2016), levels rose again and were significantly higher than all other treatments at harvest (February 6, 2017). For each sampling date, means with the same letter are not significantly different at the $\alpha \leq 0.05$ level.

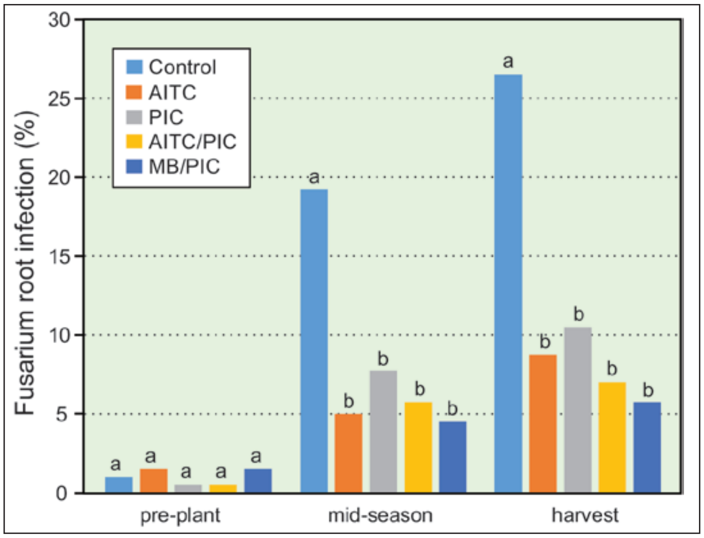

Figure 5. Soil *Fusarium* seedling root infection levels were low across all treatments prior to planting (May 2016). By late July, *Fusarium* root disease on seedlings transplanted into the nontreated control plots was significantly higher than all fumigation treatments. This pattern continued through sampling at harvest (February 2017). For each sampling date, means with the same letter are not significantly different at the $\alpha \leq 0.05$ level.

Pythium Populations

Soil *Pythium* was only observed at the preplant sampling in May 2016, during which all fumigation treatments significantly reduced soil *Pythium*, compared to the nontreated control (figure 6).

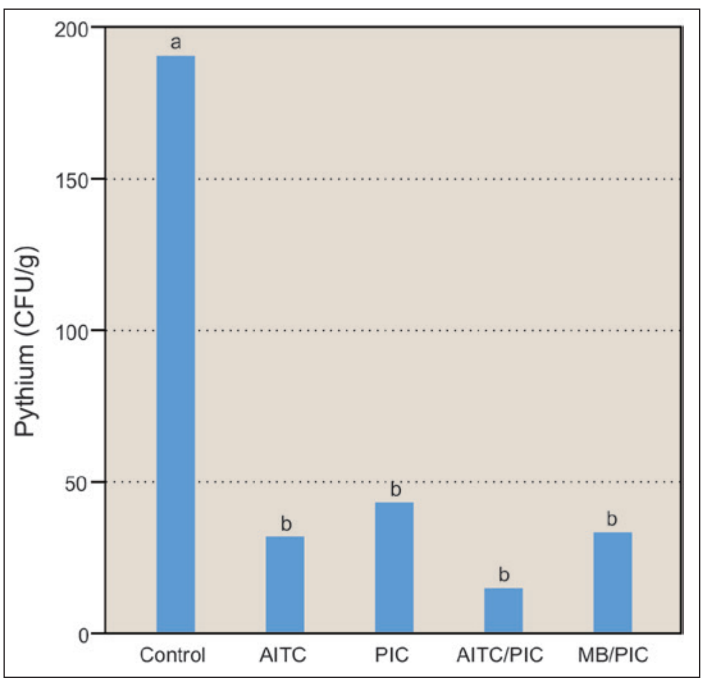

Figure 6. Soil *Pythium* was only observed at the preplant sampling (May 2016), when all fumigation treatments had significantly lower levels compared with the nontreated control. Thereafter, soil *Pythium* levels were minimal in all treatments (data not shown). Means with the same letter are not significantly different at the $\alpha \leq 0.05$ level.

Very little to no *Pythium* seedling root infection occurred during the trial for any of the treatments (data not shown).

Weeds

Treatment differences in winter annual weeds were evident soon after tarps were removed following fumigation, with treated plots showing no germination relative to nontreated areas (figure 7). The most frequent weeds recorded were *Brassica juncea* (L.) Czern. (from the cover crop) and annual bluegrass (*Poa annua* L.). In November 2015, nontreated control plots had higher weed counts than all fumigated plots (figure 8). By February 2016, weed counts in the chloropicrin alone treatment had increased to a nonsignificant difference compared with the nontreated control, but still averaged fewer weeds. All other fumigation treatments had significantly lower weed counts. Weed pressure following transplant was low throughout the growing season, and no treatment effects were observed during the July assessment (data not shown).

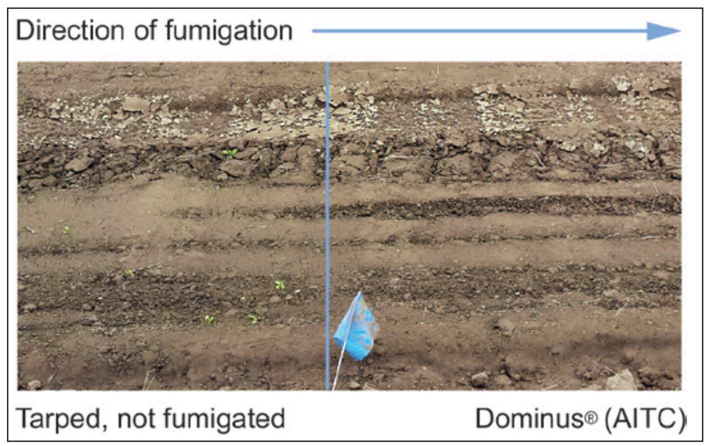

Figure 7. This photo illustrates weed germination differences within 2 weeks of removing the tarp. The area to the left was tarped, but not fumigated, and the area to the right received Dominus® (AITC) fumigation. (Photo by Nabil Khadduri)

Seedling Morphology

At planting, average seedling morphology did not differ among treatments (data not shown). At the July and November sampling, seedling height and stem diameter averaged largest in methyl bromide/chloropicrin plots, but differences in morphology throughout the trial were nonsignificant among treatments. At harvest, the root or shoot volumes among treatments had no significant differences (data not shown).

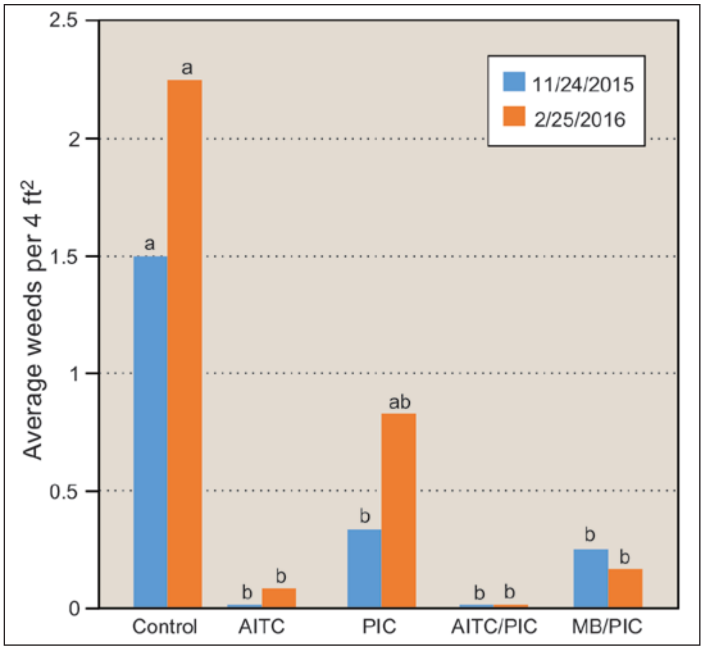

Figure 8. In November 2015 (2 months after fumigation), nontreated control plots had higher weed counts than all fumigation treatments. By February 2016, weed counts remained low for all fumigated plots, although the chloropicrin-alone treatment, while still averaging lower, was no longer significantly different than the nontreated control. For each sampling date, means with the same letter are not significantly different at the $\alpha \leq 0.05$ level.

Discussion

To our knowledge, this is the first trial with Dominus® in a conifer nursery in the Pacific Northwest and in the United States. The efficacy of the Dominus®-alone and Dominus® plus chloropicrin treatments in reducing soil *Fusarium* (and soil *Pythium* when it occurred) is encouraging. Perhaps more importantly, Dominus®, either alone or in combination with chloropicrin, maintained low levels of *Fusarium* seedling root infection. This control is on par with what would be expected with a standard methyl bromide plus chloropicrin fumigation. The results are encouraging but not entirely unexpected, as commercial isothiocyanate-based fumigants, such as metam sodium, are currently in wide use in agriculture. Weiland et al. (2011) found that a metam-sodium:chloropicrin mixture compared favorably with an operational methyl bromide:chloropicrin mixture at three forest nurseries in the Pacific Northwest. Unlike metam sodium, however, Dominus® is not subject to a fumigation management plan, restricted buffer zones, or the threat of reduced use due to commercial fumigant reregistration decisions (Isagro 2016, EPA 2017).

A concurrent study examining the use of Dominus® was conducted at a Weyerhaeuser forest seedling nursery south of Olympia, WA. This trial examined the same rates of Dominus®, with and without chloropicrin, as did the WADNR Webster study described in this article. Treatments were compared against an operational methyl bromide plus chloropicrin control. As in the WADNR Webster trial, Dominus®, both with and without chloropicrin, successfully lowered initial *Fusarium* populations to minimal levels (unpublished data). The *Fusarium* or *Pythium* populations within the soils or seedlings at any time post-fumigation had no significant differences, nor any differences among treatments for seedling height or stem diameter throughout the growing season or at harvest.

Although morphology differences were absent at both nursery studies, seedling root infection by *Fusarium* was over 25 percent at harvest in the nontreated control of this trial—several times higher than the fumigation treatments. This study did not attempt to separate either soil or seedling *Fusarium* populations into pathogenic vs. nonpathogenic categories. James et al. (2002) were the first to identify pathogenic species of *Fusarium* from forest nursery soils. For example, genetic markers can distinguish between generally pathogenic isolates of *Fusarium* commune vs. generally nonpathogenic isolates of *Fusarium* oxysporum (Stewart et al. 2006). Proportions between these pathogenic vs. nonpathogenic isolates can indicate greater or lesser risk of disease (Leon 2013). Since morphology differences were absent, it is possible that the *Fusarium* populations in this study were largely nonpathogenic. Had they been pathogenic, perhaps greater differences in morphology would have been expressed.

AITC gas is relatively immobile in the soil (Isagro 2016). Weed germination suppression following tarp removal, however, was an initial indication that the gas, at least in the loamy sand and relatively warm, late-summer conditions at application, was able to move from injection ports at 8-in (20-cm) depth to the soil surface. Nevertheless, concerns remain as to how adaptable Dominus® will be to the inevitable range of soil moisture and temperature conditions encountered in general practice. Bolda (2015) emphasizes vapor pressure of AITC gas is considerably lower than even the slower moving fumigants, such as chloropicrin or MITC agents, and the manufacturer classifies it as a "passive fumigant" (Isagro 2016).

Although this initial trial has shown promise, more testing needs to be done to demonstrate the efficacy of the product across a number of preexisting soil pathogen loads, baseline weed populations, and growing season conditions.

Future Directions

Despite these encouraging results to date, Dominus® faces two main challenges for widespread nursery use as a substitute for methyl bromide. Along with the aforementioned lack of gas mobility, which particularly limits its use in cool soil conditions, the cost of Dominus® is relatively high. Product costs in 2016 at the rates tested were 43 percent higher for the Dominus® alone application (which was applied at the maximum rate), and 69 percent higher for the Dominus® plus chloropicrin treatment, compared with the cost of the standard methyl bromide plus chloropicrin treatment ($1,860, $2,200, and $1,300, respectively). Methyl bromide and other fumigants, however, can incur increased costs, due to the necessity of having the contract fumigator visit a nursery more than once to reduce buffer zone sizes. These product costs do not include installation and TIF plastic costs of $1,200, which are the same regardless of treatment.

We plan to establish an outplant study with seedlings from this trial to evaluate whether documented pathology differences, with morphology being equal, lead to subsequent differences in outplanting performance. Ideally, baseline data on pathogenic vs. nonpathogenic proportions of the *Fusarium* populations will be determined prior to the outplant trial.

An identical trial was established in September 2016 at WADNR Webster Nursery in a higher pathogen-load field. Initial *Fusarium* reduction by Dominus® has again been dramatic, although not as low as methyl bromide plots. It will be interesting to see how trees growing in Dominus®-treated plots fare morphologically in this higher-pressure field.

A third trial is planned for late summer 2017 to address the issues of gas mobility and product cost. This trial will use a new formulation of Dominus® that has a new emulsifier adjuvant to help with gas diffusion. Perhaps more importantly, the trial will also use a tighter spacing of injection shanks, with two ports instead of one on the shanks. In theory, two shank ports will compensate for low gas mobility through improved product placement in the soil, both vertically and horizontally (Allan 2017).

The 2017 trial will also include testing at 75-percent strength rates and under cheaper tarps (HDPE vs. TIF plastics) to reduce treatment cost while maintaining efficacy through the improved emulsifier and product placement.

At some point, methyl bromide, chloropicrin, and other commercial fumigants may no longer be available to nurseries due to buffer zone restrictions or other regulations. Dominus® is a promising alternative, but must be further examined for efficacy and cost reduction before it gains widespread acceptance in the bareroot forest nursery industry.

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