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Efficacy of reduced rate fumigant alternatives and methyl bromide against soilborne pathogens and weeds in western forest nurseries

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ABSTRACT

Preplant soil fumigation is commonly used to control soilborne pathogens and weeds in forest seedling nurseries of Oregon and Washington. However, lower chemical inputs are desired to meet state and federal application regulations, to minimize buffer zone size requirements, and to help protect the environment. Therefore, the objectives of this research were to evaluate the efficacy of three reduced rate soil fumigants under totally impermeable film (TIF) in managing soilborne diseases and weeds, and to determine if combined applications of up to four biocontrol agents improved soilborne disease control. Reduced rates of methyl bromide, metam sodium, and 1,3-dichloropropene, all applied in combination with chloropicrin, were effective in decreasing soil populations of *Pythium* and *Fusarium* as well as the presence of *Pythium* in root debris from the previous crop. The roots of Douglas-fir (*Pseudotsuga menziesii*) seedlings transplanted into each fumigant treatment were also colonized less by *Pythium* and *Fusarium* than those transplanted into nonfumigated control plots. However, biocontrol treatments were not effective against either pathogen. Weed biomass and weeding times were also significantly reduced by fumigation. Application costs were similar for all three fumigant treatments, but seedling size was largest from the methyl bromide and metam sodium treatments followed by the 1,3-dichloropropene treatment. Based on the results of this study, reduced rates of methyl bromide, metam sodium, and 1,3-dichloropropene show promise in managing soilborne diseases and weeds in forest nurseries.

1. Introduction

Forest nurseries in the western states of California, Idaho, Montana, Oregon, and Washington produce approximately 200 million tree seedlings each year, mainly for reforestation purposes (Weiland et al., 2013b). Most seedlings sold in the region are Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Soilborne disease and weed control in forest nurseries has been primarily achieved through preplant soil fumigation with methyl bromide combined with chloropicrin (MBC, 67:33) at 392 kg/ha under a Quarantine Preshipment Exemption to the Montreal Protocol (Weiland et al., 2013b). The most common soilborne pathogens are those causing damping-off and root rot, such as those in the genera *Pythium*, *Fusarium*, and *Cylindrocarpon* (Dumroese and James, 2005; Stewart et al., 2011; Weiland et al., 2013a, 2011, 2013b). Typical symptoms of infection by these pathogens include chlorosis, stunting, fine root mortality, and in severe cases, seedling death. Left untreated, damping-off and root rot can significantly reduce seedling yield and quality (Stewart et al., 2011; Weiland et al., 2013a, 2013b, 2014). Eventually, forest nurseries will lose methyl bromide for disease and weed control, but in the meantime most will continue to use the product due to the lack of suitable alternatives.

Previous research in Oregon and Washington has shown that reduced rates (defined as less than label rate) of the alternative fumigants metam sodium, dimethyl disulfide, and methyl iodide, when combined with chloropicrin, are as effective at controlling *Pythium*, *Fusarium*, *Cylindrocarpon*, and weeds as the standard, full rate of MBC at 392 kg/ha (Weiland et al., 2011, 2013b). Reduced rate applications are desirable because they decrease the size of the

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required buffer zone (nonfumigated areas separating fumigated fields and neighboring property) and reduce costs because less product is applied. Unfortunately, one of the reduced rate alternative fumigants previously identified as effective, methyl iodide (iodomethane), was removed from the U.S. market in 2012, and another fumigant, dimethyl disulfide, had an objectionable, strong odor that resulted in neighbor complaints when used (Weiland et al., 2013b). As a result, there are few alternatives for replacing methyl bromide that have been tested at reduced rates in the western region of the U.S. There is also industry interest in testing the efficacy of reduced rate applications of methyl bromide because this product is still in use at approximately 70% of the region's nurseries (Weiland et al., 2013b).

Biocontrol agents have also been tested at western forest nurseries for their ability to control soilborne pathogens. For the most part, results from greenhouse and field studies have been mixed, with some treatments succeeding (Dumroese et al., 2012; Mousseaux et al., 1998), while others fail (Dumroese et al., 1996; Hildebrand et al., 2004; James et al., 2004; Linderman et al., 2008). This lack of consistency and limited success is one reason that biocontrol agents are not used more widely in forest nursery seedling production (Weiland et al., 2013b). However, previous studies mostly relied on single applications of a single biocontrol agent and there is evidence that multiple applications with several biocontrol agents might prove more effective in controlling soilborne pathogens (Guetsky et al., 2002; Whipps, 2001).

A field experiment was initiated in 2010 at two forest nurseries to evaluate reduced rate soil fumigants and biocontrol agents for efficacy against soilborne diseases and weeds. The objectives were to: (1) evaluate the efficacy of reduced rate formulations of methyl bromide and alternative fumigants in order to meet 2010 Environmental Protection Agency guidelines for a 7.6 m (25 ft) buffer zone; and, (2) determine whether applying combined mixtures of biocontrol agents can provide supplemental soilborne disease control in fumigated soils.

2. Materials and methods

2.1. Nurseries

Field trials were established at two forest nurseries (located 12 km apart) in western Oregon that had been used in previous methyl bromide alternatives research and designated nursery B and nursery C (Weiland et al., 2011). Soil at both of these nurseries is classified as Canderly sandy loam and the last crop of Douglas-fir seedlings were harvested at each nursery by March 2010. Fields at both nurseries were then bare fallow until fumigation occurred in mid-August 2010.

2.2. Experimental design

Four fumigation treatments, consisting of three fumigant treatments and a nonfumigated negative control treatment (NF), were applied under totally impermeable film (TIF) at each nursery in a randomized complete block design (RCBD) with four replicate blocks in mid-August 2010. The three fumigant treatments were: (1) 50% methyl bromide + 50% chloropicrin applied at 280 kg/ha (MBC); (2) metam sodium + chloropicrin applied at 253 l/ha and 168 kg/ha, respectively (MSC); and, (3) 40% 1,3-dichloropropene + 60% chloropicrin (Pic-Clor 60) applied at 319 kg/ha (DPC). All fumigants were selected based on their efficacy in prior industry research trials (unpublished data) and on the consensus of the two nurseries involved. Reduced rates (less than label rate) for each fumigant were selected to meet 2010 Environmental Protection Agency guidelines for a 7.6 m (25 ft) buffer zone.

2.3. Application of fumigation treatments

Fumigants were applied by a commercial applicator (Trident Agricultural Products, Toppenish, WA). Both the MBC and DPC treatments were chisel injected into the soil 23 cm deep and 30 cm apart with a D4D crawler (Caterpillar Inc., Peoria, IL) equipped with a noble plow rig. For the MSC treatment, metam sodium was injected at a 10 cm and 20 cm soil depth with a John Deere 4960 tractor (Deere & Co., Moline, IL) equipped with backswept shanks spaced 30 cm apart. Chloropicrin was then injected into the soil 23 cm deep and 30 cm apart with a D4D crawler equipped with a noble plow rig. TIF was applied immediately after fumigation to all fumigation treatment plots with the D4D crawler, including the NF plots. Fumigated plots were 46 × 13 m and NF plots were slightly shorter at 30 × 13 m to minimize economic losses due to the absence of disease and weed control provided by fumigation. This difference in size between fumigated and nonfumigated plots did not affect results as indicated by the lack of significant differences among treatment plots in both prefumigation soil pathogen populations and root debris colonization by *Pythium* and *Fusarium* (see Results). TIF was removed one month after fumigation and plots remained fallow until planting the following spring.

2.4. Planting and application of biocontrol treatments

One-year-old, bareroot 1 + 0 Douglas-fir seedlings were transplanted into each nursery in early to mid-May 2011. All plots, including the NF plots, consisted of six nursery beds with an average of 29 seedlings planted per linear 30 cm of bed. Three biocontrol treatments and a nontreated negative control treatment (no biocontrol agent) were then applied to four 7.6 × 1.2 m subplots placed according to a split-plot design in the center bed of all MSC, DPC, and NF main plots for a total of 48 biocontrol subplots at each nursery. No biocontrol treatments were applied within the MBC treated plots because methyl bromide is expected to be phased out in the future. The three biocontrol treatments were applied using hand sprinklers to their respective subplots in a 7.6 l volume of water. The biocontrol treatments were a combination of biocontrol products at soil drench label rates (Table 1) and consisted of: (1) Actinovate + Cease; (2) SoilGard + RootShield; and, (3) Actinovate + Cease + SoilGard + RootShield. The control consisted of nontreated water and was applied at the same volume/subplot. All biocontrol treatments and the control treatment were applied three times throughout the 2011 growing season: early June, late July to early August, and early October.

2.5. Soilborne and seedling pathogens

Soil in each of the 16 fumigation plots (4 fumigation treatments × 4 blocks) at each nursery was assessed for soilborne pathogen populations (*Pythium*, *Fusarium*, and *Cylindrocarpon* species) two weeks before fumigation (prefumigation, late July 2010), six weeks after fumigation (postfumigation, late September 2010), just before planting (preplant, mid-May 2011), and at the end of the growing season (harvest, early-to mid-December 2011). Soil samples were collected by taking twenty 2-cm-diameter × 30-cm-depth soil cores in a randomized pattern from each plot. Soil samples from the biocontrol subplots were obtained using the same sampling strategy, but were only collected at harvest. Soil samples were bulked by plot or subplot and mixed thoroughly to generate composite samples for each fumigation plot and biocontrol subplot at each nursery. Half of each composite soil sample was then plated on PARP (Kannwischer and Mitchell, 1978) to assess *Pythium* soil populations and the remaining half was plated on Komada's medium (Komada, 1975) to assess *Fusarium* and