CHALLENGES IN PRODUCING NEMATODE- AND PATHOGEN-FREE FRUIT AND NUT NURSERY CROPS IN THE UNITED STATES

Inga A. Zasada, Nematologist, USDA-ARS Horticultural Crops Research Laboratory, 3420 NW Orchard Ave., Corvallis, OR 97330 USA, Thomas W. Walters, Horticulturist, WSU-NWREC, 16650 State Rt. 536, Mount Vernon, WA 98273 USA, and Bradley D. Hanson, Weed Scientist, University of California, Davis, Department of Plant Sciences MS-4, One Shields Ave., Davis, CA 95616 USA consider the problems associated with finding effective alternatives to methyl bromide for control of nematodes and soil-borne pathogens in US fruit and nut nursery crops

Keywords: soil-borne pathogens, methyl bromide, chloropicrin, fumigant, management

Introduction

The 2006 gross value of fruit and nut nursery crops in the United States was $276 million (USDA, 2007). This category includes citrus and subtropical fruit trees, deciduous fruit and nut trees, grapevines, and other small fruit plants, such as raspberry and strawberry. California produces the majority of the fruit and nut nursery stock sold in the United States, with Oregon and Washington also producing a significant proportion. A critical component in the production and sale of these nursery crops is the generation of planting stock that is free of viruses, soil-borne pathogens, and plant-parasitic nematodes.

To achieve plant-parasitic nematode and soil-borne pathogen control, fruit and nut nursery crop producers have relied upon preplant soil fumigation with combinations of methyl bromide and chloropicrin (Figure 1). This method allows the producer to reduce significantly or eliminate plant-parasitic nematodes and soil-borne pathogens and helps mitigate the risk of developing infected plant material. Methyl bromide is classified as a restricted-use pesticide and was registered for use in the United States in 1961 (US EPA, 1986) as an effective herbicide, nematicide, insecticide, and fungicide. In the late 1980s and early 1990s, methyl bromide was one of the five most used pesticides in the United States, with 75% of the use being for preplant soil fumigation (Ristano & Thomas, 1997). Despite the widespread use of this pesticide, methyl bromide was targeted for phase-out under the Montreal Protocol due to its ability to deplete stratospheric ozone. However, the Montreal Protocol allows for critical use exemptions (CUE) to the ban if 1) there are no technically and economically feasible alternatives that are acceptable from a regulatory and bystander exposure perspective, and 2) the use is considered crucial to avoid a significant market disruption of selected commodities (UN, 2006). Since this time, US fruit and nut nurseries have been able to obtain CUEs to continue to use methyl bromide. Nurseries in the United States have also qualified for quarantine/preshipment exemptions based upon import regulations requiring that plants be grown in soil fumigated with methyl bromide.

Methyl bromide has several characteristics that led to its widespread use, including broad-spectrum pest control, greater efficacy in comparison to other fumigants (McKenry, 1994) and a volatility sufficient to penetrate soils some distance from points of application (Duniway, 2002). Due to these attributes, fruit and nut nursery crop producers have relied upon, and continue to use, methyl bromide. However, under the Montreal Protocol the availability of methyl bromide will continue to decline and use of the fumigant will ultimately cease. Therefore, other nematode and soil-borne pathogen management practices must be identified and integrated into fruit and nut nursery crop production systems. Perennial fruit and nut nursery crops can provide a difficult test of otherwise effective alternative fumigants because of the extremely low tolerance for nematode infestation and because the relatively long growing cycle requires pest control efficacy at soil depths of 1.5 m or greater (Schneider *et al.*, 2009a). Below we outline the current status of methyl bromide alternative research in two nursery crop production systems each possessing its own unique challenges.

Figure 1. Bed fumigation (foreground) versus broadcast fumigation in Washington (photo taken by J. Gigot)

California Fruit and Nut Nurseries

California nurseries account for approximately 60% of the total fruit and nut plants sold in the United States. In-ground

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Figure 2. Harvest of bare-root fruit and nut nursery stock in California (photo taken by B.D. Hanson)

production of deciduous fruit and nut trees (Figure 2) is a major component of this nursery sector and largely supplies planting material for the increase and maintenance of nearly 486,000 ha of bearing stone fruit (peach, plum, apricot, nectarine, etc.) and tree nuts (almond, pistachio, pecan, walnut) in California alone (USDA, 2010). Open field production of grapevine nursery stock accounts for much of the planting stock supporting over 320,000 ha of wine, table, and raisin vineyards in California. California nurseries also ship fruit and nut crop nursery stock throughout the United States and around the world.

Soil fumigation prior to planting high-value nursery crops is critical to California nursery production for two main reasons. From an agronomic standpoint, soil fumigation provides control or suppression of a broad spectrum of soil-borne pests including pathogens, plant-parasitic nematodes, and weeds. Control of these pests ensures a vigorous start to propagated orchard and vineyard stock and can greatly reduce production costs in a cropping system that has relatively few post-plant chemicals available for the control of plant-parasitic nematodes and soil-borne pathogens. Second, and more importantly, in order for a California nursery to sell stock outside the county of origin, the plants must be "commercially clean with respect to economically important nematodes" (CDFA, 2010a). These regulations have been enacted to ensure that nematodes such as root lesion (*Pratylenchus* spp.), root-knot (*Meloidogyne* spp.), and dagger (*Xiphinema* spp.) are not spread from infested nurseries to production fields and that the establishment and vigor of new production fields is not compromised.

Nematode certification in California can be met by either fumigating the field using an approved treatment (Table 1) or by conducting a detailed inspection of soil samples and planting stock at the end of the production cycle (CDFA 2010a, 2010b). If a grower elects to meet certification requirements using the robust inspection procedures and prohibited nematodes are found in soil or plant samples, further sampling is conducted to delineate the extent of the problem. Nursery stock from the affected area cannot be sold for commercial farm planting and is usually destroyed. Thus, preplant soil fumigation reduces the economic risk of a non-saleable nursery crop and is used by nearly every commercial perennial crop nursery in the state of California.

Methyl bromide has long been the most common treatment used to meet certification requirements and growers are familiar with field preparation requirements and appreciate the broad spectrum control of both nematodes and other less regulated pests such as crown gall (*Agrobacterium tumefaciens*) and annual and perennial weeds. For some soil texture and soil moisture conditions, 1,3-dichloropropene (1,3-D) is an approved soil treatment for certified nursery production in California (CDFA, 2010a). However, the maximum use rate of 1,3-D in California does not provide sufficient nematode control in nurseries with fine textured soils (McKenry & Thompson, 1974). Use of 1,3-D in California is further restricted by township caps (a township is a geographically defined area six-by-six-miles square) that are shared by all 1,3-D-using crops on a first-come-first-served basis (CDPR, 2002). Although metam sodium and chloropicrin are currently registered in the United States and have provided nematode, pathogen, or weed control in trials in various nursery production systems (De Cal *et al.*, 2004; Porter *et al.*, 2006), they are not currently approved for certified nursery production in California. Iodomethane, which is currently undergoing the registration process in California, has shown promise in open-field nursery trials, as well as other trials (Becker *et al.*, 1998; Eayre *et al.*, 2000).

Raspberry Nurseries

Raspberry nurseries located in Washington and California provide plants to a $231 million red raspberry fruit industry with 5,900 ha of production in the United States (USDA, 2010). California raspberry nurseries are subject to the same intercounty shipment restrictions as other fruit and nut nurseries (see above). Raspberry plants grown in California and Washington are also often shipped to Canada, Mexico and elsewhere, and plants for international shipments must be grown in fumigated soil to comply with import requirements. Another reason for preplant soil fumigation is that raspberry nurseries must produce disease-free plants to avoid disease outbreaks in raspberry production fields. However, it is difficult to prevent disease spread via nursery plants completely because they can harbor latent, or asymptomatic, infections. Simply removing plants with visible disease symptoms is not enough, so most nurseries focus on avoiding critical pathogens

Table 1. Susceptibility of soil-borne pathogens and root lesion nematode to methyl bromide alternatives in a raspberry nursery trial in Washington. A plus (+) indicates that the treatment reduced soil-borne pathogen survival to less than 10% of survival measured in a non-treated soil, while a minus (–) indicated that the treatment did not reduce soil-borne pathogen survival compared to survival in a non-treated soil

Treatment	Root rot (*Phytophthora rubi*)	Crown gall (*Agrobacterium tumefaciens*)	Root lesion nematode (*Pratylenchus penetrans*)
Non-treated with Virtually Impermeable (VIF) tarp	–	–	–
1,3-dichlorpropene:chloropicrin 65:35 (365 L ha^{-1}) with High Density Polyethylene (HDPE) tarp	+	–	+
Telone C-35 (1,3-dichlorpropene) (365 L ha^{-1}) with VIF	+	+	+
Iodomethane:chloropicrin 50:50 (392 kg ha^{-1}) with HDPE	+	+	+
Iodomethane:chloropicrin 50:50 (196 kg ha^{-1}) with HDPE	–	–	+
Iodomethane:chloropicrin 50:50 (196 kg ha^{-1}) with VIF	–	–	+
Methyl bromide:chloropicrin 67:33 (392 kg ha^{-1}) with HDPE	+	+	+

Table 2. Currently approved treatments for nematode certification on field-grown, 26-month nursery stock in California (CDPR, 2010a)

Methyl bromide tarped with High Density Polyethylene (HDPE) tarp. Application rates vary with soil type: sandy (336 kg ha^{-1}) and clay loam (448 kg ha^{-1}).

Methyl bromide, dual application. At least 7 d after 1st treatment plow to flip soil and retreat with 2nd application. Application rates vary with soil type: sandy (336 + 168 kg ha^{-1}) and clay loam (448 + 168 kg ha^{-1}).

1,3-D, untarped dual application. At least 14 d after 1st treatment plow to flip soil and retreat with 2nd application. Application rates vary with soil type: sandy (319 kg ha^{-1} + 159 kg ha^{-1}) and not approved for use on clay loam soils.

1,3-D, tarped with HDPE. Application rates vary with soil type: sandy to sandy loam (372 kg ha^{-1}) and not approved for use on clay loam soils.

1,3-D applied to sandy to sandy loam soil (372 kg ha^{-1}) followed with 130 kg ha^{-1} a methyl isothiocyanate generator 7-21 days later. This application is not approved for use on fine textured or moist soils.

1,3-D applied to sandy to sandy loam soil (372 kg ha^{-1}) coapplied with 130 kg ha^{-1} MITC generator. This application is not approved for use on fine textured or moist soils.

through site selection, rotation, and soil fumigation. Nurseries choose production fields without a history of dangerous pathogens (e.g. *Phytophthora rubi*, causing raspberry root rot) and select for well-drained soil types that are less favorable for disease development. Unfortunately, the sandy soils preferred by raspberry nursery growers to minimize damage by root rot may favor plant-parasitic nematodes. Nurseries generally practice crop rotation, keeping a three to five years interval between raspberry nursery plantings.

Raspberry nursery growers in the United States tend to be conservative in their choice of soil fumigants and have been slow to adopt alternatives to the effective combination of methyl bromide and chloropicrin. This treatment controls the major nematode problems for raspberry nurseries, root lesion and dagger nematodes. Methyl bromide and chloropicrin also controls other important soil-borne pests of raspberry nurseries, including Phytophthora root rot, crown gall, and weeds. Recent evidence suggests, however, that viable alternatives to methyl bromide exist for raspberry nursery production (Table 2). Full and reduced rates of a combination of iodomethane and chloropicrin eliminated root lesion nematode, as did 1,3-D:chloropicrin 65:35. Control of root rot and crown gall required the full rate of iodomethane or required that 1,3-D:chloropicrin be applied under a highly retentive barrier such as virtually impermeable film (VIF). However, results can vary with soil conditions and nurseries are understandably reluctant to give up a fumigant such as methyl bromide that has been an industry standard for decades.

Future challenges

Fruit and nut nursery crop producers have been able to rely upon a remarkably robust soil fumigant, methyl bromide, to control soil-borne pathogens, plant-parasitic nematodes, and weeds. The future challenges that these industries will face include adopting and integrating relatively new technologies to control soil-borne pests into existing production systems, the potential economic constraints associated with these new technologies, and a constantly changing landscape of fumigant registration and application requirements in the United States. These challenges will be exacerbated by high phytosanitary requirements in California and in countries importing nursery plants from the United States.

In the short-term, fruit and nut nursery crop industries will continue to rely upon chemical nematode control. Currently, there are only a handful of chemicals registered for preplant nematode and soil-borne pathogen control (Tables 1 and 2). None of the identified alternatives can replace all methyl bromide use in fruit and nut nurseries immediately because they have significant technical and regulatory limitations.

In 2009, the US Environmental Protection Agency (US EPA, 2010) issued re-registration eligibility decisions for the fumigants chloropicrin, metam sodium, metam potassium, methyl bromide, and dazomet. Regulatory changes, including buffer zone requirements, are mandated to appear on the fumigant pesticide labels in 2010 and 2011, and the US EPA plans to initiate registration reviews for all of the soil fumigants in 2013, four years earlier than previously planned (US EPA, 2010). Adoption of 1,3-D may be limited by this fumigant's chemical properties, as it is much less volatile than methyl bromide and will not readily fumigate soil that is too wet or cold (McKenry & Thompson, 1974). Reduced volatility also results in a relatively long plant-back time compared to methyl bromide. In addition, township caps in California limit the amount of 1,3-D that may be used in any township. Recently, California released a proposed decision to register iodomethane (CDPR, 2010). If registered in California, regulatory target levels and mitigation strategies will be more stringent than those for the 47 other states in which iodomethane is registered for use on vegetables, turf, and fruit and nut nursery crops (US EPA, 2009).

One often overlooked attribute of broadcast fumigation with methyl bormide is the fact that growers need not have an appreciable understanding of the mechanism of pest control. Decades of use and refinement of application rates and techniques, plus the unique chemical properties of methyl bromide, have given growers a pest management tool that disperses quickly through the soil profile, performs well in a range of soil texture and moisture conditions, and quickly and reliably kills whatever soil-borne pests are present. In the absence of methyl bromide, growers will need to be sensitive to the conditions under which individual fumigant and combinations of pest management practices will be successful.

Technologies that reduce fumigant emissions will need to be employed to minimize bystander exposure and reduce buffer zone sizes. Examples include: low-permeability plastic films, water treatments, bed fumigation, chemigation, and coapplication with organic materials such as composted manure (Gao *et al.*, 2010; Schneider *et al.*, 2009b). The ability of a nursery grower to implement these technologies will ultimately be driven by economics and performance. The tolerance for prohibited pests is extremely low in nursery stock from both a regulatory and business reputation standpoint. Emission mitigation procedures that reduce fumigant dispersal or residence time in very shallow or deeper soil layers may not provide a sufficiently high level of nematode or soil-borne pathogen control for nursery production of deep-rooted fruit and nut nursery stock.

As US nursery growers step into the relatively unknown territory of new fumigants, and perhaps, ultimately, no fumigants, they will need to rely upon unfamiliar management practices to make the best use of currently available chemical and non-chemical pest management systems. Current research and outreach efforts are focused on maximizing efficacy and grower familiarity with available chemical alternatives. However, much more work is needed to test and develop new products and techniques for control of prohibited pests in nursery production.

The economic and environmental costs of producing nematode and pathogen-free nursery stock are difficult to estimate. It is clear that fumigating a few thousand hectares of nursery stock annually can provide a hundred-fold increase in economic and productivity benefits to the many hectares of production orchard, vineyard, and berry crops dependent on clean nursery stock worldwide. The greatest challenge to production of plant-parasitic nematode- and pathogen-free nursery stock in the future will be finding solutions that simultaneously meet: 1) the high pest control efficacy needs of nursery producers; 2) very specific nursery certification requirements; 3) evolving regulatory requirements related to environmental quality; 4) worker and bystander safety concerns; and 5) federal and state registration of fumigant pesticides. While this is certainly a formidable task, the potential costs of wide spread plant-parasitic nematode or soil-borne pathogen problems in nursery and production fruit and nut crop industries in the United States is tremendous.

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Inga Zasada is a Research Plant Pathologist/Nematologist at the USDA-ARS Horticultural Crops Research Laboratory, Corvallis, OR. Her research focuses on the management of plant-parasitic nematodes in small fruit production systems.

Thomas Walters is an Assistant Scientist and Extension Specialist at Washington State University's Northwestern Washington Research and Extension Center, Mt. Vernon, WA. His research and extension programs concern berry crop production and physiology, with a focus on management of soil-borne disease in berry crops.

Brad Hanson is a Cooperative Extension Specialist in Weed Control in the Department of Plant Sciences at the University of California, Davis. His recent research has focused on methyl bromide alternatives and integrated pest management in perennial crop nurseries, weed control in orchard and vineyard production systems, and herbicide-resistant weeds.

Letter to the Editor

In his August 2010 letter to the editor (RE: Golf at a Crossroads: Hazardous or Healthy Strategies) Dr. Lorne Hepworth argues that pesticides are "safe." His letter targets the associations between pesticides and cancer that we of Rachel Carson Council identified in our article and that are based on references from government and academic research sources. His rejection of a possible pesticide cancer link is a simplistic, sweeping statement made without any references whatsoever.

He further fails to disclose that he is the president of CropLife, Canada, a pesticide industry trade association.

In a recent issue of *Environmental Health Perspectives* researchers from Health Canada published a review of pesticide exposure and cancer incidence that presents relevant observations, suggesting that further evaluation of registered pesticides is warranted. The authors conclude that "positive exposure-response relationships [for human cases of cancer] were observed for 12 pesticides… [and] particular attention should be paid to registered pesticides that displayed evidence of a possible association with carcinogenicity." (Weichenthal *et al* 2010)

Dr. Hepworth apparently believes in the stringency of Canada's regulatory system. With the benefit of this new scientific reference, we would hope that Dr. Hepworth could use his office as president of a crop protection organization to urge caution, further research and support for low risk alternative pest management methods for golf courses.

We note in addition, that a number of Canadian municipalities have initiated restrictions surpassing those required by Health Canada on the use of cosmetic pesticides with the purpose of protecting human health and the environment.

Sincerely,
Diana Post, VMD

Weichenthal S, Moase C, Chan P. 2010. "A Review of Pesticide Exposure and Cancer Incidence in the Agricultural Health Study Cohort." *Environmental Health Perspectives* 118:1117-1125. doi:10.1289/ehp.0901731