PREPLANT FUMIGATION ONLY TEMPORARILY REDUCES NORTHERN ROOT-KNOT NEMATODE

Authors: Michelle M. MOYER[*1], Maria MIRELES[1], Bernadette GAGNIER[1], Katherine E. EAST[2], and Inga A. ZASADA[3]

[1]*WSU Prosser IAREC, 24106 North Bunn Road, Prosser, WA, 99350, USA*
[2]*USDA-Horticultural Crops Production and Genetic Improvement Research Unit, 24106 North Bunn Road, Prosser, WA 99350, USA*
[3]*USDA-Horticultural Crops Disease and Pest Management Research Unit, 3420 NW Orchard Ave, Corvallis, OR 97330, USA*

*Corresponding author: *michelle.moyer@wsu.edu*

Abstract:

Context and purpose of the study - Management of plant-parasitic nematodes is typically focused on preplant fumigation, especially in a vineyard replant scenario. While the data are clear that this practice reduces nematodes immediately after application, which is useful in annually-cropped systems, does it have staying power in perennial cropping systems? The northern root-knot nematode *Meloidogyne hapla* reduces the overall lifespan and productivity of vineyards, but it does so over a long time period (slow, chronic decline). In two different commercial own-rooted *V. vinifera* vineyards, both undergoing vineyard replanting, we explored whether preplant fumigation reduced *M. hapla* densities in soils immediately after application. At one of these locations, we have explored the long-term effect of fumigation by monitoring the site for seven years post fumigation.

Material and methods - This trial was conducted at two commercial vineyards in eastern Washington State (USA). Both sites were previously planted to own-rooted *V. vinifera,* and were being replanted (in part) to own-rooted *V. vinifera*. ***Vineyard 1*** – Old vines were removed in fall 2018, and the site was fumigated with 1,3-dichloropropene (1, 3-D) soil injection in spring 2019; nonfumigated areas were also included in the trial. The site was replanted in August 2019. ***Vineyard 2*** **–** Older vines were treated with foliar glyphosate, and the soil fumigated with drip-applied metam sodium in fall 2014; nonfumigated areas were also included in the trial. Vines were removed over the winter, and the site was replanted in spring 2015. At both locations, soil samples for *M. hapla* enumeration were collected prior to fumigation, and every spring and fall post-fumigation. Nematode densities and nematode dosage were used to evaluate the effects of fumigation on subsequent nematode development on own-rooted *V. vinifera* vines.

Results - The fumigation with either 1,3-D or metam sodium had varying levels of efficacy at reducing *M. hapla* densities within 6 months of treatment ($p = 0.31$ Vineyard 1; $p = 0.04$ Vineyard 2) relative to non-fumigated plots. At both locations, in fumigated plots, total *M. hapla* densities reached preplant fumigation levels in own-rooted vines within 18 months post-fumigation ($p = 0.94$, Vineyard 1; $p = 0.10$ Vineyard 2). In Vineyard 2, after 7 years post-fumigation, there was no difference in nematode densities between fumigated and non-fumigated plots, and own-rooted vines showed equivalent levels of decline relative to vines planted on nematode-tolerant rootstocks that were also included in these trials. These results suggest that preplant fumigation alone is not a long-term control option for the management of *M. hapla*, and the adoption of resistant or tolerant rootstocks, along with other cultural control methods, will be needed for successful vineyard replanting.

Keywords: Rootknot Nematode, fumigation, rootstocks, own-rooted, Integrated Pest Management

1. Introduction

The northern root-knot nematode (*Meloidogyne hapla*) is the primary plant-parasitic nematode affecting Washington state own-rooted *Vitis vinifera* vineyards (Zasada et al., 2012). *M. hapla* reduces the overall lifespan and productivity of *V. vinifera* (East et al., 2021; Jenser et al., 1991; Ramsdell et al., 1996) through the continued development of small but damaging galls on growing root tips (Howland et al., 2015).

The most commonly-implemented management of soilborne pests in vineyards includes preplant soil fumigation of the site to eliminate the pest prior to planting (Raski 1955), and/or the adoption of resistant or tolerant rootstocks to reduce the likelihood of vine decline if the pest is present (McKenry et al. 2001, Nicol et al., 1999; Sauer, 1967). The latter approach presents two production challenges. First, not all rootstocks are created equal for their resistance or tolerance to different nematode species (e.g., Anwar et al., 1999; McKenry et al., 2001, Stirling and Cirami, 1989, Téliz et al., 2007). Second, not all grape growers choose to use rootstocks, preferring own-rooted vines for horticultural reasons such as adaptation to alkaline soils or the ability to retrain after damaging winter cold events (Keller et al., 2012; Moyer et al., 2019). In Washington State, until recently, own-rooted vines were also preferred due to the general lack of established phylloxera (*Daktulosphaira vitifoliae*) (Chandel et al., 2022).

As a result, Washington grape growers have primarily focused their nematode management strategies on the use of pre-plant fumigation. But is fumigation really a long-term management option when growing a perennial crop? Fumigation only impacts the soil that is treated; thus, its effects can be limited in space (depth and width of fumigation). Many plant-parasitic nematodes, especially those that impact grape, are mobile in the soil and can have wide host ranges. Nematodes may quickly reinvade previously-fumigated locations. In this study, we explored how long preplant fumigation lasts, using two different fumigant chemicals and application strategies in vineyards undergoing replanting.

2. Material and methods

Vineyard 1 – Own-rooted *Vitis vinifera* 'Cabernet Sauvignon' vines (30+ years) were removed in fall 2018, and the site was fumigated with 1,3-dichloropropene (1,3-D; Telone II) in spring 2019. Fumigation was applied at a rate of 327 L/ha (35 gal/acre), injected into the soil in 3 m wide swaths. Fumigated and non-fumigated swaths were alternated across the vineyard block. The site was replanted to both own-rooted and rootstock-grafted Cabernet Sauvignon in fall 2019. All rootstocks were planted consecutively along a vineyard row, with four vines per rootstock. Rootstocks plots were replicated three times within fumigated and non-fumigated areas.

Vineyard 2 – This vineyard is the site of a previously published research trial (East et al., 2021). This site was intended to be a part of a long-term (10 year) trial. In summary, own-rooted *V. vinifera* 'Chardonnay' vines (20+ years) were treated with foliar glyphosate, and the soil fumigated with drip-applied metam sodium in fall 2014 (*as described in East et al., 2021*). Vines were removed over the winter, and the site was replanted to both own-rooted and rootstock-grafted Chardonnay vines in spring 2015.

Data collection and statistical analysis – The focus of this presentation is how fumigation impacts *M. hapla* population densities in own-rooted *V. vinifera* vineyards. In both vineyards, soil cores were collected prior to fumigation, and in the spring and fall post-fumigation, for enumeration of *M. hapla* 2nd-stage juveniles (free-living stage). Soil cores were collected directly under the irrigation drip emitters; cores were approximately 2.5 cm by 25 cm, and 10 soil core composites were taken from each plot. Nematodes were extracted from soil using a semi-automated elutriator (Seinhorst, 1962) and sugar flotation and centrifugation (Zasada et al., 2012). In Vineyard 1, the fall 2019 soil sample was not elutriated, but rather, planted to a highly suseptible 'Roma' tomato to conduct an *M. hapla* egg bioassay. This assay is used in for soils where very low *M. hapla* J2 populations are expected. Nematode densities and nematode dosage (East et al., 2021) were used to evaluate the fumigation effects. Analysis of variance was used with soil treatments as fixed effects, and field blocks (replicates) as random effects. Mean separation was evaulated using Tukey's HSD.

3. Results and discussion

3.1*. Preplant fumigation provided inconsistent suppression of* M. hapla *in own-rooted vineyards within the first growing season.*

In Vineyard 1, the effect of pre-plant fumigation with shanked-in 1,3-D on *M. hapla* densities in the soil was minimal 6 months after fumigation and 2 months after planting the susceptible Cabernet Sauvignon vines ((fall 2019, Fig. 1A). However, it would have likely been interpreted as effective had a grape producer collected a soil sample, given the large differences in nematodes reproduction (using the tomato bioassay) from non-fumigated soils relative to fumigated soils. The mean number of *M. hapla* from the tomato bioassay, between the two soil treatments, did not reach a level to be interpreted as statistically significant, likely given the large variance in nematode densities seen across the vineyard; aggregate distribution of nematodes is common in vineyard settings which can increase the variance between soil samples.

In Vineyard 2, 6 months (spring 2015) after drip-application of metam sodium, there was a reduction in *M. hapla* densities in fumigated soli relative to non-fumigated soil ($p = 0.04$), and this effect was still present at 12 months post-fumigation (fall 2015) ($p < 0.0001$). Densities of *M. hapla* continued to increase from the pre-planting starting point, and well-surpassed the accepted threshold of 100 *M. hapla* J2/ 250 g soil (Fig. 2A).

The difference in results between the two locations likely highlights potential differences in the efficacy of fumigation chemistries (1,3-D or metam sodium), or the differences in the application approaches (injected into the soil or applied through the existing drip irrigation infrastructure). While large-area injections might appear to provide broader control, application of a product through the existing drip would place it directly where most nematodes are concentrated (East et al., 2019), and if applied properly in an irrigation cycle, may be able to reach deeper into the soil profile relative to the limited vertical distribution of injected products.

3.2. *The effects of preplant fumigation on* M. hapla *control were lost in own-rooted* Vitis vinifera *vineyards by the second growing season.*

In Vineyard 1, the effects of preplant fumigation was lost by the end of the second growing season (Fig. 1B). This was maintained through the end of the third growing season (Fig. 1C). In fact, the average *M. hapla* densities seen in the second growing season had surpassed the threshold of 100 *M. hapla* J2 / 250 g soil by that second growing season.

In Vineyard 2, the effects of preplant fumigation was also lost 18 months post-fumigation, which was also the start of the second growing season (spring 2016) ($p = 0.1$). In the years following, *M. hapla* population densities mirrored each other in the fumigated and non-fumigated areas within the vineyard, just offset by a year or two (Fig. 2A). At some of the sampling dates there was a large increase in *M. hapla* soil densities in fumigated areas, likely indicating a boom-and-bust population dynamic relative to other predatory soil microbes and the development (and loss) of available fine root tips for feeding. Another way to look at the long-term effects of chronic nematode exposure is to see it expressed as nematode dosage (Fig. 2B), where you can quickly see that after only a few years, own-rooted vines in fumigated soils were experiencing the same degree of nematode pressure as vines in non-fumigated soil.

These results can be troubling to those growers who have own-rooted *V. vinifera* vineyards, as the post-plant chemical options for management of plant-parasitic nematodes are limited in their efficacy (East et al., *unpublished*; Martin et al., 2022). Cultural approaches, such as the use of suppressive cover crops, might be the only remaining solution for the interim suppression of plant-parasitic nematodes in own-rooted vineyards. These results also provide incentive to adopt the use of tolerant or resistant rootstocks as a primary approach for mitigating decline related to the feeding of plant-parasitic nematodes, particularly, *M. hapla.*

4. Conclusions

Preplant fumigation alone is not a long-term control option for the management of *M. hapla* (northern root-knot nematode) in vineyard replant scenarios in Washington State. Perennial cropping systems need longer-term approaches for management of plant-parasitic nematodes, and this is one of the few studies that have followed the efficacy of fumigation in a vineyard system over several years. While noted in other regions,

the adoption of resistant or tolerant rootstocks, along with other cultural control methods, will be needed for successful vineyard replanting in Washington, and is an approach that was not previously considered in the state.

5. Acknowledgments

Funding for this project was provided through the Washington State Grape and Wine Research Program, including Washington State Wine Commission, Auction of Washington Wines, State Liter tax, and/or WSU Agriculture Research Center. This research was also partially funded by USDA-ARS Current Research Information System 2072-22000-043-00D and USDA National Institute of Food and Agriculture Hatch project 1016563.

6. Literature cited

Anwar S.A., McKenry M.V., Kaku S., 1999. Resistance of ten grape rootstocks against six *Meloidogyne* spp. J Nematol. 31, 522.

Chandel A.K., Hoheisel G.A., Moyer M.M., Keller M., Khot L., 2022. Soil and Climate GIS Data-Derived Risk Mapping for Grape Phylloxera in Washington State. Front. Plant Sci. 13, 827393.

East K.E., Moyer M.M., Madden N.M., Zasada I.A., 2019. How low can they go? Plant-parasitic nematode distribution in a Washington vineyard. Catalyst: Disc. Pract. 3, 31-36.

East K., Zasada I., Tarara J., Moyer M., 2021. Field performance of wine grape rootstocks and fumigation during establishment of a Chardonnay vineyard in Washington. Am. J. Enol. Vitic. 72, 113–125.

Howland A.D., Skinkis P.A., Wilson J.H., Riga E., Pinkerton J.N., Schreiner R.P., Zasada I.A., 2015. Impact of grapevine (*Vitis vinifera*) varieties on reproduction of the northern root-knot nematode (*Meloidogyne hapla*). J. Nematol. 47, 141–147.

Jenser G., Debaj K.H., Lehoczky J., 1991. The effect of the northern root-knot nematode (*Meloidogyne hapla* Chitwood) as a possible cause of unsuccessful replanting of vineyards on sandy soil. Növényvédelem 27, 62–65.

Martin K., Brannen P.M., Holladay T., Severns P.M., 2022. Nonefficacy of postplant nematicides in *Vitis vinifera* wine grapes in Georgia, USA. Plant Health Prog. 22, 499-455.

McKenry M.V., Kretsch J.O., Anwar S.A., 2001. Interactions of selected *Vitis* cultivars with endoparasitic nematodes. Am. J. Enol. Vitic. 52, 310–316.

Moyer M.M., Mills L.M., Hoheisel G.A., Keller M., 2019. Assessing and managing cold damage in Washington Vineyards. WSU Extension Publication #EM042e. Washington State University, Pullman, WA.

Nicol J.M., Stirling G.R., Rose B.J., May P., Van Hesswijck R., 1999. Impact of nematodes on grapevine growth and productivity: current knowledge and future directions, with special reference to Australian viticulture. Aust. J. Grape Wine Res. 5, 109–127.

Ramsdell D.C., Bird G.W., Warner F.W., Davenport J.F., Diamond C.J., Gillett J.M., 1996. Field pathogenicity studies of four species of plant-pathogenic nematodes on French-American hybrid grapevine cultivars in Michigan. Plant Dis. 80,334–338.

Raski D.J., 1955. Control of nematodes on grapes: Soil fumigation with crop rotation tested as a way to protect grape replants against root parasites. Cali. Ag. 1 (January), 9–15.

Sauer M.R., 1967. Root knot tolerance in some grape vine rootstocks. Aust J. Exp. Agric. Anim. Husb. 7, 580–583.

Seinhorst J.W., 1962. Modifications of the elutriation method for extracting nematodes from soil. Nematologica 8, 117-128.

Stirling G.R., Cirami R.M., 1984. Resistance and tolerance of grape rootstocks to South Australian populations of root-knot nematode. Aust. J. Exp. Agric. Anim. Husb. 24, 277–282.

Téliz D., Landa B.B., Rapoport H.F., Camacho F.P., Jiménez-Díaz R.M., Castillo P., 2007. Plant-parasitic nematodes infecting grapevine in southern Spain and susceptible reaction to root-knot nematodes of rootstocks reported as moderately resistant. Plant Dis. 91, 1147–1154.

Zasada I.A., Riga E., Pinkerton J.N., Wilson J.H., Schreiner R.P., 2012. Plant-parasitic nematodes associated with grapevines, *Vitis vinifera*, in Washington and Idaho. Am. J. Enol. Vitic. 63, 522–528.

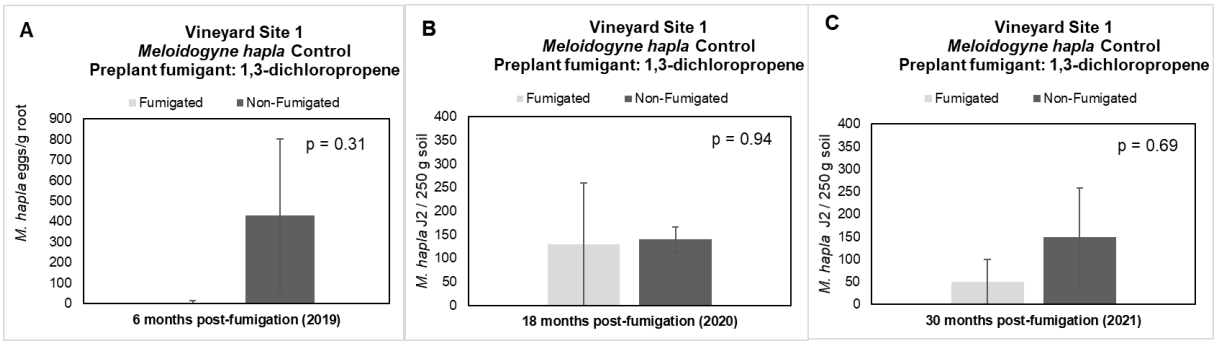

Figure 1: Preplant fumigation with 1,3-dicholoropropene did not provide long-term suppression of *Meloidogyne hapla* in a vineyard replant scenario when own-rooted *Vitis vinifera* 'Cabernet Sauvignon' was planted. **(A)** Six months after fumigation, initial results appeared to show a small fumigation effect, even though vines weren't planted into the site until 4 months post-fumigation and 2 months prior to fall soil sampling. **(B)** By the end of second growing season there was no longer any treatment effect. **(C)** This lack of effect was seen by the end of the third growing season.

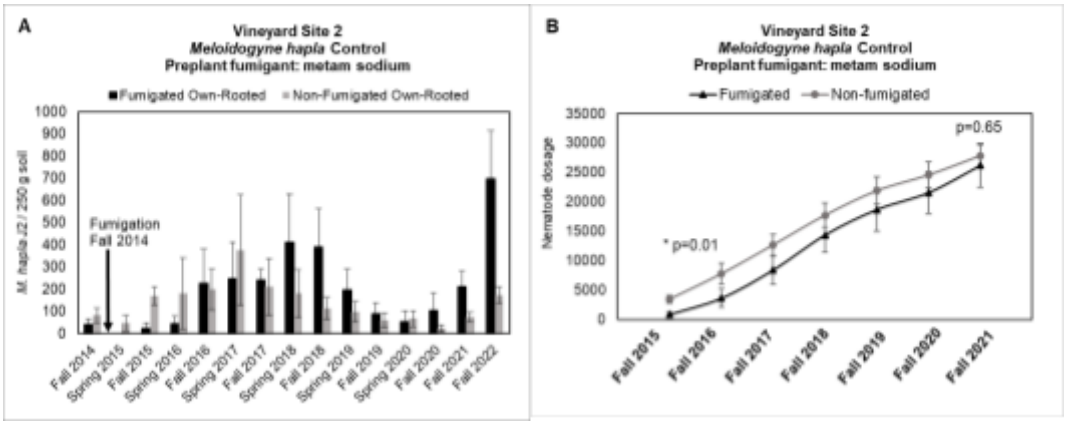

Figure 2: The effects of drip-applied metam sodium in Vineyard 2 did not last long for *Meloidogyne hapla* management. **(A)** While fumigation initially reduced *M. hapla* densities in the soil, these effects were lost by the start of the second growing season. For the next several seasons, nematode population dynamics between the fumigated and non-fumigated locations mirrored each other, with nematode densities in the fumigated soils often exceeding those in non-fumigated soils. **(B)** At the end of the 7th growing season, the accumulated nematode pressure (nematode dosage) between fumigated and non-fumigated sites for own-rooted *V. vinifera* 'Chardonnay' were not statistically different.