Washington State Grape and Wine Research Program

FINAL REPORT - SUMMARY

Project Title: Impact of Plant Parasitic Nematodes on Grapevine Growth and Development in Washington

Principle Investigator: Michelle M. Moyer

Summary:

Decisions for managing plant-parasitic nematodes in Washington wine grapes have been historically made with very little information regarding nematode biology or lifecycle. As the industry enters a time of replanting, and the use of preplant fumigants becomes increasingly challenging due to regulation, knowing how to best manage this pest is paramount for sustainable grape production. This project looked at several key aspects in plant-parasitic nematode biology and management strategies, to build a better understanding of how to best optimize our approaches for reducing vine loss due to nematodes. First, we evaluated three different cultural practices that could be used to mitigate nematode decline in newly-planted vineyards: rootstocks, irrigation, and fertilization (nitrogen). We learned that the biggest impact, in terms of reducing nematode development after planting, is achieved by using resistant rootstocks as the primary cultural practice, rather than the adoption of altered irrigation or fertilizer (nitrogen) regimes to stimulate vine vigor. Second, we continued to monitor a large-scale rootstock trial at a commercial vineyard where we learned that preplant fumigation has a very limited efficacy period (6 months post planting), and that visible decline symptoms of early nematode infestation in a replanted block take up to 5 years to manifest (typically at a time when the vineyard should be reaching peak productivity). This continuing trial is a unique experience, in that we now have a "tool" (a vineyard) to monitor the long-term impacts of nematodes and preplant fumigation on vine establishment and productivity. Trials that are limited to short-term resistance evaluations fail to capture the long-term consequences of chronic exposure to a pest, which is the more common situation in perennial cropping systems. Finally, we continued to evaluate the performance of different post-plant nematicides, where we learned that manufacturer's timing recommendations were not aligning with nematode biology in this state. Many of the products that targeted the mobile root-knot nematode second-stage juvenile (J2) stage were being applied to late in the spring to have an impact the majority of the J2 populations. Products that were ovicides (targeted to eggs) were labeled to be applied in the spring and fall, but not when eggs are present (mid-summer). These misalignments with target nematode biology may be one of the reasons why past efficacy trials did not look promising – the products were simply not being recommended for the appropriate time when they would be most efficacious.

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Project Duration: 3 years, FY18-20, 1 July 2017- 30 June 2020

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Objective(s) and Experiments Conducted to Meet Stated Objective(s): The report objectives should match the objectives in the original proposal.

The objectives outlined below were designed to provide new information on the effectiveness of chemical and cultural strategies to manage plant-parasitic nematodes. Having this information would improve the efficiency of the current cultural tools Washington growers have for nematode management and add additional chemical tools from which to select.

Objective 1- *Evaluation of vine response to nematodes under varying population densities, nutrient and irrigation regimes, and rootstocks.* The goal of this objective was to evaluate the influence of different cultural practices on vine response during establishment exposed to a range of nematode densities. The cultural practices evaluated were use of rootstocks, different irrigation regimes and different nitrogen regimes (**Figure 1; next page**).

Figure 1 – This was a 3-part objective. The first (left) evaluated the response of own-rooted Chardonnay vines exposed to different nematode densities while being watered under different irrigation regimes. The second (center) evaluated the performance of different rootstocks under different nematode densities. These two trials were completed at WSU Prosser. The third (right) evaluated the growth response of own-rooted Chardonnay under different nematode densities when managed with different nitrogen fertilizer regimes. This greenhouse experiment was completed at USDA-ARS in Corvallis, OR.

Experiment 1: Challenge rootstocks with a range of M. hapla *densities to examine the durability of resistance*. The experimental vineyard was established on-site at WSU Prosser IAREC in May 2017. Vines were planted in a nursery-like fashion with 1 ft between vines (plots consisted of 6 vines) and 4 ft between plot. Each plot (rootstock + nematode density) was replicated 4 times. Vines were standardized to 2 shoots at the beginning of the growing season. Rootstock treatments consisted of own-rooted Chardonnay and Chardonnay grafted on the rootstocks Matador, 1103 Paulsen and 3309 Couderc. The site was supplemented with soil from a nematode infested vineyard, as well as inoculated with *M. hapla* eggs at the time of planting, which allowed us to challenge the vines at 3 levels of *M. hapla* (derived from naturally infested soil (1,180 J2 per 250 grams) through a series of mixing with sterile soil). The nematode densities used were: 1) no nematodes; 2.5 L of control soil; end density of 0 J2 per 250 g soil; 2) medium density; 0.5 L of inoculation soil and 2.0 L control soil; end density of 50 J2 per 250 g soil; and 3) high density; 2.5 L inoculation soil; end density of 250 J2 per 250 g soil. Water was applied to vines via drip irrigation, with emitters placed directly over vines, and no water applied to the space between vines.

After establishment in spring 2017, the following data was collected: 1) *Nematode population density.* One soil core per plant (1”-diam. x 12”-deep) was collected from directly under the drip emitter and cores combined. Nematodes were extracted using a semi-automatic elutriator (Seinhorst 1962). In the spring and fall, J2 population densities were enumerated from these

soil cores. In the fall, roots were retained from the elutriation process and eggs were bleach extracted from roots and counted. 2) *In-season vine growth.* Total shoot length was determined in fall 2017 and 2018. 3) *Total plant growth.* Root and shoot biomass, and fine root tip density was taken via destructive sampling in fall 2017 and fall 2018. With destructive sampling, 3 vines were removed from each plot in 2017, leaving 3 vines for the 2018 growing season. 4) *Dormant pruning weights.* Vines not destructively sampled in fall 2017 were pruned to 2 buds and dormant pruning weights were collected (winter 2017).

Experiment 2: Determine if water availability and irrigation affect the host-parasite interaction in establishing vineyards. In the same field as above, another plot of own-rooted Chardonnay on 4 ft between vines and 6 ft between in-row planting density was used. Irrigation treatments were: 1) Full irrigation (irrigated to keep soil water potential above -100 kPa); 2) Mid-season reduction (starting approximately 1 Aug; irrigated when soil water potential reached -500 to -600 kPa).; and 3) Mid-season cut-off (approx. 1 Aug; irrigated only when soil water potential < -1000 kPa). Timing of irrigation cut-off was designed to coincide with the timing of increasing *M. hapla* J2 populations in the soil, based on our previous work (East et al. 2019). Dielectric soil water potential sensors (MPS-6; Decagon Devices) were used to measure soil water potential and schedule irrigation at least twice a week. When average soil water potential reached a treatment threshold, those plots were watered, generally returning them to field capacity (-33 kPa). Total water applied in each season is shown in Table 1. The soil moisture profile was refilled prior to irrigation shut off (19 October 2017) to maintain enough moisture going into winter. As for Exp 1, sub-treatments consisted of 3 densities of *M. hapla.* The irrigation + nematode density plots (9 treatments = 3 irrigation x 3 nematode densities) were replicated 4 times.

After establishment in spring 2017, the following was collected: 1) *Nematode population density* (as described above) in spring and fall of both 2017 and 2018. 2) *In-season vine growth.* Total shoot length in fall 2017 and 2018. 3) *Total plant growth.* Root and shoot biomass, and fine root tip counts via destructive sampling in fall 2017 and fall 2018. And; 4) *Dormant pruning weights.* Vines not destructively sampled in fall 2017 were pruned to 2 buds and dormant pruning weights were collected (winter 2017).

Experiment 3: Determine if vine nutritional status (particularly nitrogen) changes the host-parasite interaction and improves vine tolerance to M. hapla *during vineyard establishment.* To determine the effect of vine nutrition on *M. hapla* in grape, a potted vine trial was established in Apr 2018 at the USDA-ARS Horticultural Crops Research Laboratory in Corvallis, OR, in two separate experiments, one established on 12 Apr 2018, and the other on 16 Apr 2018. These experiments were established and maintained separately. Dormant Chardonnay vines were sorted by diameter into bundles of 6, three of which received *M. hapla* and three which did not. Each group of three was split into high, medium, and low nitrogen

treatments (roughly equivalent to 5 lbs/acre [control], 10 lbs/acre and 30 lbs/acre of N). Eight replicate vines per treatment were used, for a total of 48 potted vines per experiment. Vine roots were trimmed to approximately 15 cm in length, and roots above the main root mass were removed. A 1:1 silt:loam soil was mixed in a soil mixer. In the *M. hapla* treatment (+ nematode), *M. hapla* eggs (96,000 eggs) were added to the mixer and distributed throughout the soil. In 7.5-L pots, soil was added into the bottom of the pot and a trimmed vine was placed into the pot. Vine roots were inoculated with arbuscular mycorrhizal fungi (AMF) by shaking 50 mL of inoculum over wet roots. In the *M. hapla* pots, additional *M. hapla* J2 were inoculated over roots by pipetting 6 mL (2,000 *M. hapla* J2) over roots. Approximately 4,000 eggs and 2,000 J2 were inoculated per pot. The rest of the pot was then filled with soil over the top of roots, shaken down, and filled again. Vines were watered, conditioned in a greenhouse, and then moved to an outdoor pot lot in May. Vines were maintained outside for five months until fall 2018, when nematode samples were taken, vines were then put into cold storage for winter, and taken back out in spring 2019 to repeat the nitrogen treatments a second year. Pruning weights were determined in year 1 and the experiments were destructively harvested at the end of the second year. At this time *M. hapla* J2 and egg densities were determined as described above. Other data collected included shoot, root, dry leaf, dry trunk weights.

Objective 2 - *Longer-term evaluation of impact of plant-parasitic nematodes on vineyard establishment and productivity.* This objective was designed to evaluate the long-term efficacy of replant recommendations (fumigation, rootstocks) for nematode management **(Figure 2; next page**).

This site was monitored for nematode population dynamics and associated vine yield-growth responses. This included spring and fall soil sampling to determine nematode population densities and fall root sampling to determine *M. hapla* egg numbers within all the rootstock plots. We also collected dormant pruning weights on 10 vines per rootstock plot, monitoring whole-vine yield on those same 10 vines per treatment replicate. In total, there are 720 data vines in this research trial. In 2019 we also began sampling for vine nutrient status (via tissue testing) and began preliminary evaluation on root association with arbuscular mycorrhizal fungi (AMF); we are still evaluating and interpreting these results (i.e. not presented below). Previous work has demonstrated that AMF colonization is enhanced when less water is applied to Cabernet Sauvignon vines, allowing for more efficient nutrient uptake by grapevines (Schreiner et al, 2007); however, this site is typically not managed under long-term deficit irrigation, and thus, high levels of association may not be present.

Figure 2 – This trial was established in spring 2015 in Paterson, WA as a randomized split-block design consisting of 6 main rootstock treatments (Chardonnay as the scion) replicated 4 times. Treatments consisted of entire vine rows. The rootstocks evaluated were: 101-14 Mtg, Harmony, 1103P, Teleki 5C, and own-rooted. All 5 rootstocks (including own-rooted) were bench grafted. A 6th treatment, (non-grafted own-rooted control) was included in the experimental design. Nested within each rootstock treatment were fumigated and non-fumigated plots (half of each row). Fumigation (Vapam, 75 gal/acre) was drip-applied in fall 2014. Within the non-fumigated plots, additional subplots include inoculation of supplemental root-knot nematodes at planting.

Objective 3 - *Evaluate the effectiveness of post-plant nematicides under Washington vineyard conditions (FY 18 only).* The goal of this objective was to evaluate the effectiveness of various pre-registration and existing post-plant nematicides (**Figure 3**).

Figure 3 – Post-plant nematicides were applied via the "cup" method to mimic chemigation. Product applications are generally applied in the last quarter of the irrigation set. This allows sufficient pre-wetting of the soil, but also prevents the product from leaching through the root zone.

These evaluations were done in 2 different commercial vineyard sites, following manufacturer recommendations. Five nematicide treatments were evaluated, alongside a non-treated control. Product treatments are replicated 4 times. Products evaluated were: Movento (Bayer), Movento + Velum Prime (Bayer; unlabeled for grape), Velum Prime (Bayer; unlabeled for grape), Test

Product B (Corteva; in final development with expected registration for grapes in 2021 or 2022), and Nimitz (Adama, not labeled) (**Table 1**). Movento was only used at our Horse Heaven Hills site. The unlabeled products have the potential for being labeled for grapes, but more testing data is needed to encourage such labeling. All products (except Movento) were applied through the drip line in accordance to the manufacturer's instructions. Treatments consist of 5 to 18 vines in a row (site dependent). In each row, a 5 to 10-vine section were identified for repeated soil sampling. Each sample was comprised of 5 to 10 cores (1"-diameter *x* 15" deep) collected directly below the emitter. Plots were sampled three times per year: in the spring, mid-season, and in the fall. The number of *M. hapla* J2/250 g soil were determined as described above. Fruit from non-registered product treatments were destructively evaluated. Plant evaluation consisted of: yield per vine, cluster weights and pruning weights taken on 3 to 5 vines per treatment replicate (site dependent).

Table 1 – Application rates and timing of post-plant nematicides in summer 2017 (FY18).

Product	**Rates**	**Timing**	**Application**
Nimitz	3.00 ai / ac	Apr	Drip
Test Product B	61.4, 30.7, 30.7 fl oz /ac	Apr, May, Jun	Drip
Velum Prime	6.84 fl oz/ ac	Apr, Oct	Drip
Movento	6.25 fl oz product / ac	May, Jun	Foliar
Velum Prime + Movento	6.84 fl oz/ ac + 6.25 fl oz / ac	Apr, Oct + May, Jun	Drip + Foliar
Control	n/a		Drip

Summary of Major Research Accomplishments and Results by Objective:

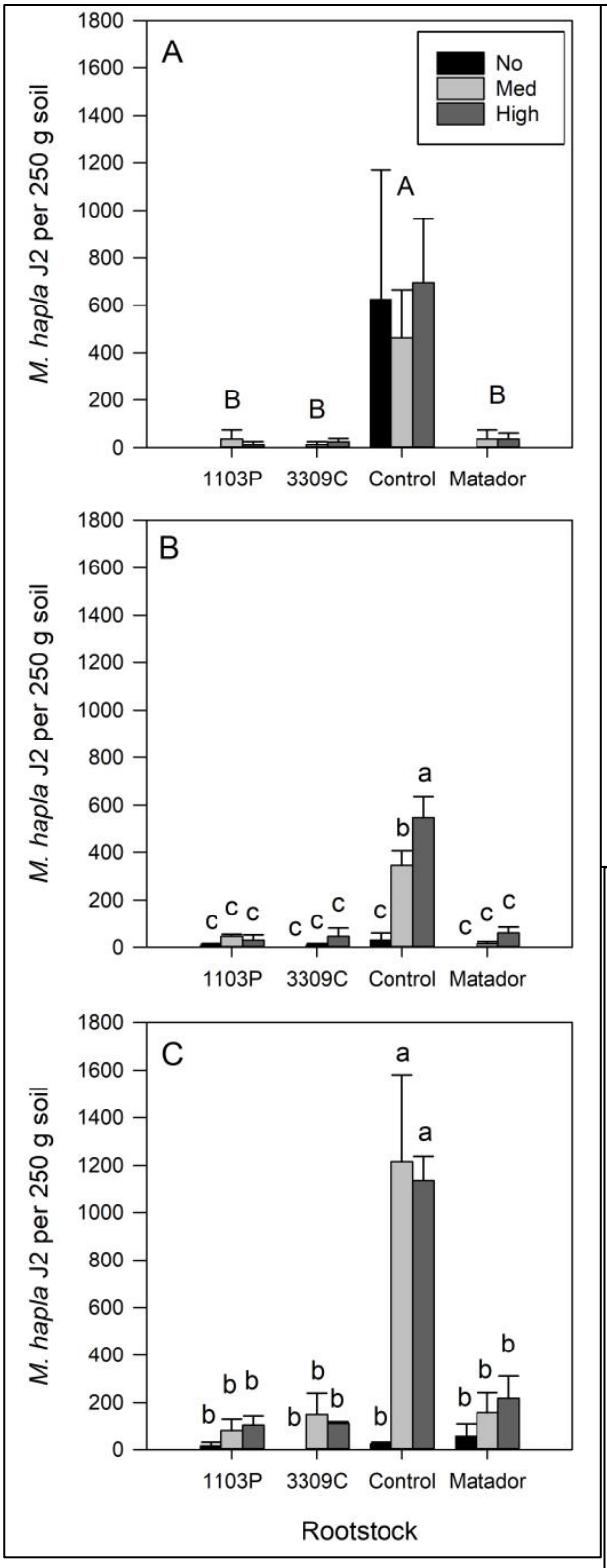
Objective 1 - *Evaluation of vine response to nematodes under varying population densities, nutrient and irrigation regimes, and rootstocks.*

Accomplishments. In our first subobjective, we saw that the adoption of resistant rootstocks helped suppress the build-up of the northern root-knot nematode (*M. hapla*). In addition, the rootstocks were more vigorous than own-rooted vines (likely due to their nematode resistance and lack of decline symptoms). This has an additional benefit aside from increased vineyard longevity, in that it would allow the grower to push that new replant vineyard to production capacity more quickly than would be possible with own-rooted vines. In our second subobjective, we saw that if nematodes are present at the time of planting, they continue to build during the first two years of vine growth on own-rooted vines. We also saw that irrigation regimes (full irrigation, partial irrigation, or a more classic RDI) did not influence nematode development. This indicates that varying irrigation regimes in own-rooted vines in the presence of nematodes does not offer a viable post-plant nematode-induced decline management option. In our third subobjective, our aim was to determine if vine nutritional status could overcome *M. hapla* feeding damage. We

found that this was not the case, with little interaction between nematodes and nitrogen rate in our analyses. As expected, vines that receive more nitrogen grew better, regardless of nematode feeding. However, this was a short-term pot study, and our field trial suggest that multiple years of nematode feeding may be needed before damage is noticeable in the plant.

Results.

Objective 1.1 (rootstocks) – Own rooted vines, as expected, consistently supported reproduction of *M. hapla* (**Figure 4; next page**). While there appears to be some cross-contamination in the no-nematode added plots in year 1 (could also be a data coding error), in subsequent sampling, we also see a clear difference in the rate of nematode increase, as it relates to starting populations – the higher the initial population density, the more quickly it builds. We also see this trend in our in-ground rootstock trial (data in Objective 2), but populations appear to reach a "bust" peak before the crash and eventually settle at a level that may be related to a population maintenance threshold. There was no effect of nematode density on vine biomass within rootstocks, but there was a biomass difference between rootstocks (**Figure 4; next page**). Pruning weights from the dormant 2017-2018 season displayed a similar pattern where the control (own-rooted) vines had significantly lower pruning weights than the rootstocks (*data not shown).*



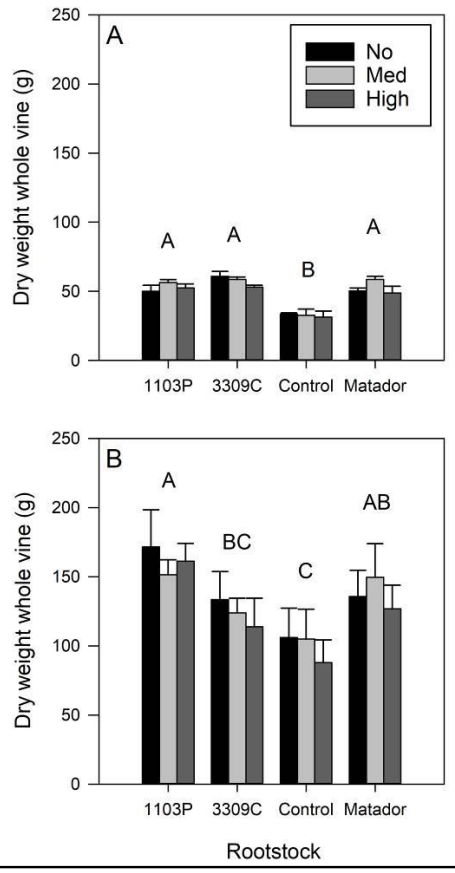


Figure 4 – Rootstock response to nematode pressure at the time of planting. Bar color denotes nematode densities. Different letters denote significant differences between treatment means at α = 0.05 using Tukey's HSD; lower case denotes significant differences in rootstock*nematode treatment, and upper case denotes significant differences only between rootstock treatments. **Left** – Own-rooted vines consistently hosted more nematodes than the rootstocks. (A) Fall 2017; (B) Spring 2018; (C) Fall 2018. While nematode populations maintained very low levels in the different resistant rootstocks, they steadily increased in the own-rooted vines. **Right -** Dry weight by rootstock (A) Fall 2017; (B) Fall 2018. Within a rootstock, there were no nematode-related differences in biomass, but between rootstocks, the own-rooted vines were consistently less vigorous.

Objective 1.2 (irrigation) – In this experiment, which was on own-rooted vines, there was no effect of irrigation treatment on *M. hapla* nematode densities in either fall 2017 (p=0.6) or fall 2018 (p=0.9). The initial nematode densities (none, moderate, high), followed their starting trends through the experiment, in that by fall 2018, there were significantly more nematodes in the high starting populations, than in the moderate or no starting population densities. We saw a difference in dormant pruning weights (2017-2018 winter), where vines with full irrigation (regardless of nematode density) did have higher pruning weights (p=0.0002) than those on a partial or low irrigation regime. However, by fall 2018, there was also no difference in vine vigor, as measured by dry biomass, as a result of irrigation (p=0.8) or nematode treatment (p=0.06).

Objective 1.3 (nitrogen) – At the end of the first year of the experiments, only nitrogen treatment had a significant impact on pruning weights (p=0.047). Vines that received low nitrogen had lower pruning weights than vines that received moderate and high nitrogen. At the end of the experiment, there were more *M. hapla* eggs on vines that received high nitrogen than on vines that received low nitrogen (p=0.044). There was no impact on nitrogen treatment on juveniles in soil. Dry shoot and root weights were both only impacted by the main effect of nitrogen treatment (p<0.001), with both being higher in vines that received high nitrogen Similar to our irrigation trials above, we are concluding that the use of nitrogen, or mitigating potential decline symptoms by increase fertilization, is not a solution for reduce nematode build up and mitigate of post-plant nematode decline of vines. While the vines did initially grow better under higher nitrogen (as expected), the potential longer-term impact that may include the ability to support a higher development rate of nematodes is not understood.

Objective 2 - *Longer-term evaluation of impact of nematodes on vineyard establishment and productivity.*

Accomplishments. We have clear evidence that fumigation is only a temporary fix for *M. hapla* but appears to be very effective against dagger nematodes (*Xiphinema* spp.). We also have evidence that decline symptoms related to root-knot nematode feeding take several years to manifest, i.e., that the latent period before symptom expression is long. This can result in a false sense of efficacy for replant management strategies.

Results. For dagger nematode, it was 3.5 years after fumigation before nematodes returned to the fumigated plots (Fall 2014 to Spring 2018) (**Figure 5; next page**). However, at the time of sampling in Fall 2019, dagger nematode densities were still 5x less than what they were prior to fumigation in own-rooted plots. This indicates that the practice of pre-planting fumigation is effective at maintaining low dagger nematode numbers through the establishment years of a new vineyard; however, dagger nematode is also sensitive to soil

disturbance, and the act of removing the existing vineyard prior to replant likely played a significant role in reducing initial nematode populations. Unfortunately, all the rootstocks evaluated in this trial were hosts for dagger nematode at a level similar to own-rooted vines.

For *M. hapla*, however, preplant fumigation was not as effective (**Figure 5**), lasting only 1 year after application, and the effect being gone by Spring 2016 (p=0.18). Five years post-fumigation (Fall 2019), nematode populations densities in own-rooted vines in fumigated plots have returned (and have been at such a level for a couple of years) to preplant levels. In non-fumigated plots, initial nematode levels steadily built up to high levels peaking in Fall 2017, but have since declined, likely settling at a population-density steady-state that match pre-trial levels. This has us question some of our prior notions on what a "threshold" is for nematodes. Historically, the typical threshold numbers presented are based on levels

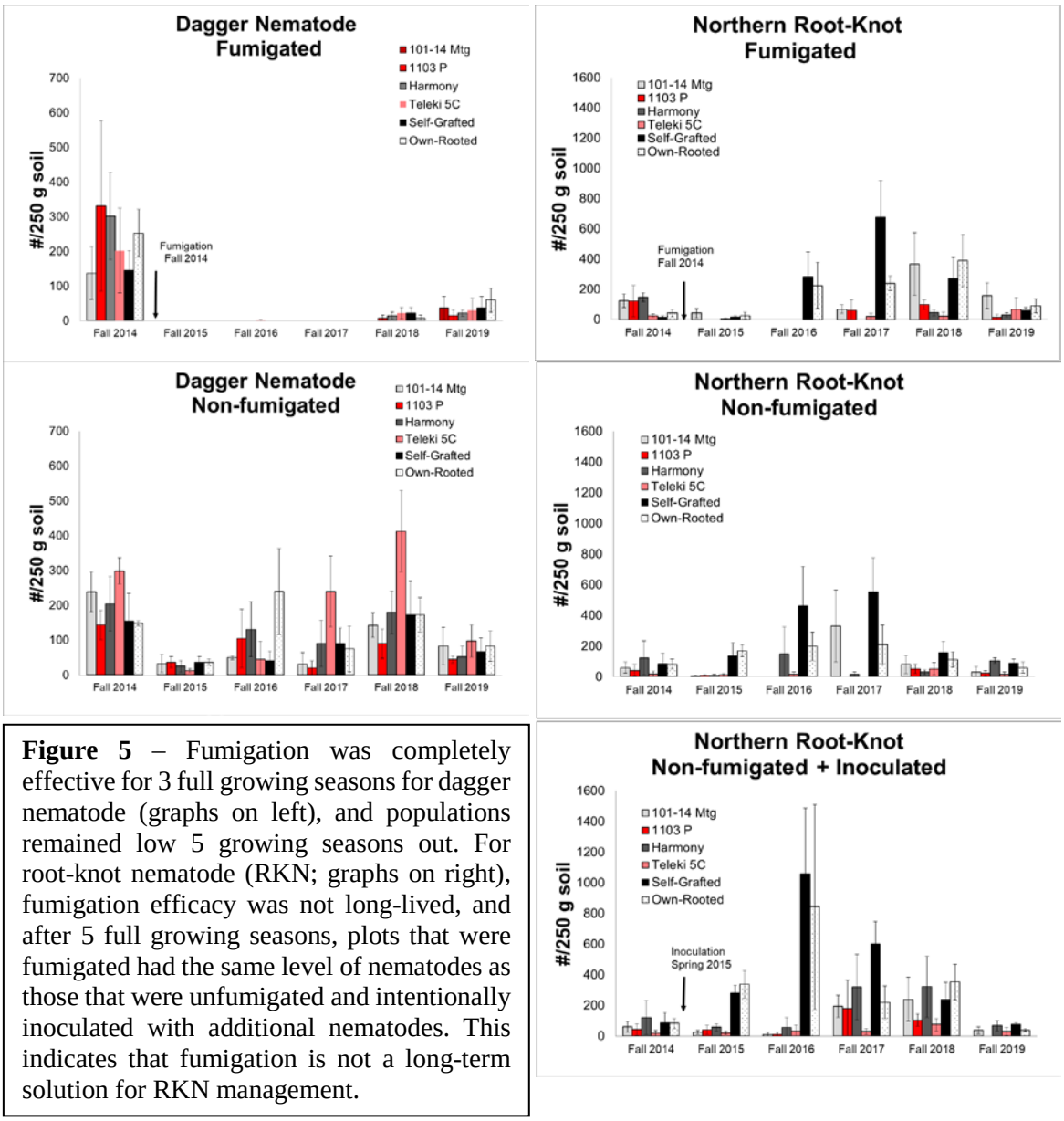


Figure 5 – Fumigation was completely effective for 3 full growing seasons for dagger nematode (graphs on left), and populations remained low 5 growing seasons out. For root-knot nematode (RKN; graphs on right), fumigation efficacy was not long-lived, and after 5 full growing seasons, plots that were fumigated had the same level of nematodes as those that were unfumigated and intentionally inoculated with additional nematodes. This indicates that fumigation is not a long-term solution for RKN management.

that are seen in older, established vineyards. But perhaps, there is no set threshold number, as it varies with vine age and other site characteristics (and stresses). We are reconsidering the threshold concept based on this data, to one that instead reflects a baseline population that would support a sudden rapid increase in population (i.e., a percent change in a short period of time, rather than an absolute threshold number) and subsequent vine response.

Rootstock differences in nematode host status were gone by Fall 2019 (p=0.08). In other words, these rootstocks also appear to be maintenance hosts for *M. hapla* under field conditions, but they have not displayed above-ground symptoms of decline. We often refer to this as "moderately" resistant – the nematodes are able to reproduce, at a reduced rate, but the plant does not initially show any decline symptoms. In fact, the rootstocks were often more vigorous (higher pruning weights) than the own-rooted vines (**Figure 6**).

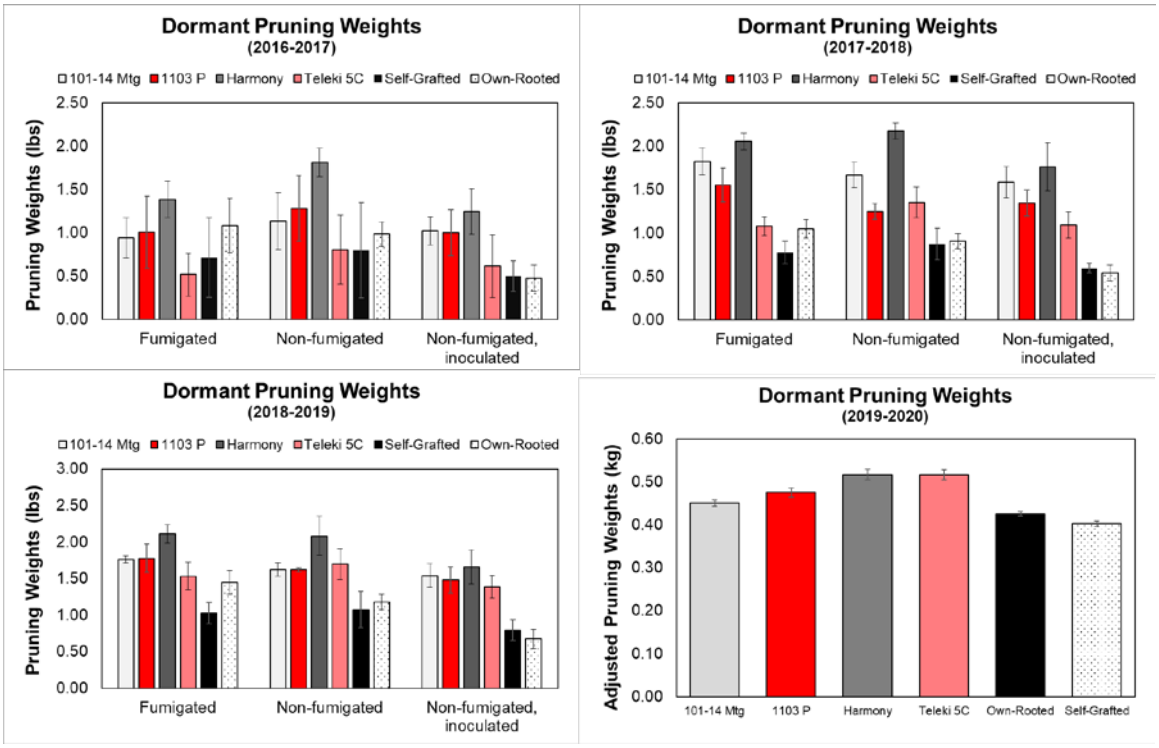


Figure 6 – Influence of soil pretreatment and rootstock choice on vine vigor, as measured by dormant pruning weights. Note, in 2019-2020, the block was mistakenly pre-pruned, but vigor differences were still noticeable. By 2019, the own-rooted vines were less vigorous than Harmony and Teleki 5C.

This might be the primary way these rootstocks mitigate the effects of nematode feeding; through enhanced vine vigor. While soil pretreatment did statistically influence pruning weights in 2016-2018 (as well as rootstock choice), by 2019, soil treatment effects were gone (p=0.72) and only rootstock genetics influenced pruning weights (p=0.0004).

In 2017, soil pretreatment did not influence yield (p=0.55), but rootstock did (higher yields in Harmony than Teleki 5C and 101-14 MTG – all others were intermediate). In 2018, the effect was swapped where soil pretreatment did influence yield (p = 0.02), but rootstock did not (p=0.06, although we would likely consider this an effect). In 2019 neither soil pretreatment (p=0.08) or rootstock (p=0.22) influenced yield. These differences across the first 3 cropping seasons of the site are likely related to management practices; the grower does practice crop thinning, and this was done throughout the plots. However, crop thinning was more about reducing number of clusters per vine, and if reduced vigor continues, we will likely also start to see smaller cluster weights on own-rooted vines, which may result in a consistent re-emergence of reduced yield on those rootstocks. In all years of the study, we saw no statistical differences in harvested fruit brix, TA, or pH, and they all fell within acceptable ranges for Chardonnay in Washington.

Objective 3 - *Evaluate the effectiveness of post-plant nematicides under Washington vineyard conditions (FY 18 only).*

Accomplishments. As with past nematicide trials, at best, we have seen inconsistent efficacy of post-plant nematicides, especially when using softer chemistries. We have yet to see a yield increase in vines treated with post-plant nematicides, and we expect that this will be a common challenge with the use of post-plant nematicides to reduce nematode-induced decline symptoms. In these cases, even if the products were effective, it may take multiple years of repeated application and nematode control before vigor is recovered (if recovery is even possible). This might be reflective of this "threshold" concept – that in established vineyards, likely ones that have already gone through a boom-and-bust cycle of nematode development, the long-term damage has already been done and the use of post-plant nematicides will not be effective. This may suggest that even with post-plant products, their application may need to start immediately after a replant, to help prevent that boom in population development. The effective chemistries appear to have many years before registration on grape or are having some difficulties reconciling dosage that is effective against nematodes but does not elicit a phytotoxic response in the plant. These trials highlight the challenges in responding to nematode infestations once they are present, and emphasize the role of pre-planting strategies (e.g., fumigation, rootstock selection) on successful vineyard nematode management. These trials also highlighted that many of the labeled manufacturer timings do not align with nematode biology in Washington – they were developed with biological data from California, which often has different nematode species (and subsequent life stage patterns), than our species here in Washington.

Results. Overall, the use of post-plant nematicides did not result in a rapid reduction in resident nematode populations (**Figure 7).** In the Horse Heaven Hills, Treatment B (a

Corteva Product; will be labeled under the name “Salibro”) and Velum Prime reduced overall nematode populations from the time of trial establishment.

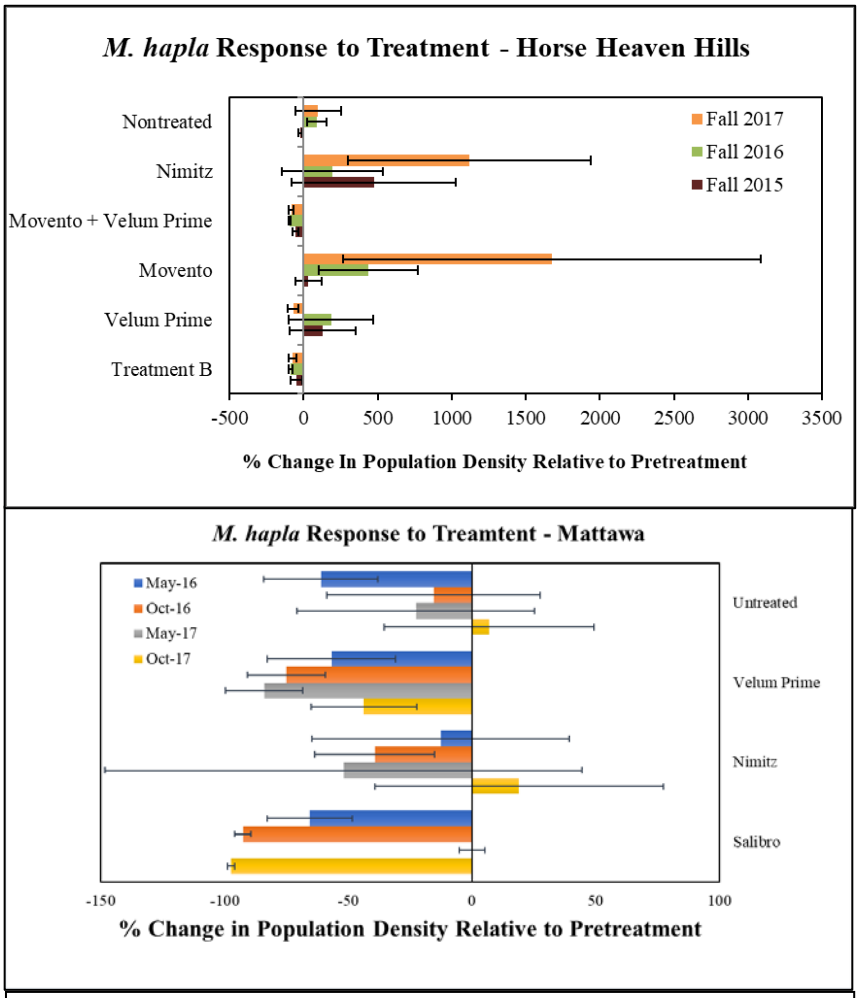


Figure 7 – Influence of post-plant nematicide applications on change in nematode population over time at two sites – Horse Heaven Hills (top), and Mattawa, WA (bottom). Salibro (a new Corteva product) was the most consistently promising, and new studies are now evaluating rates at timing of application.

Unfortunately, Velum Prime also elicited severe phytotoxic responses (mimicked phenoxy herbicide exposure) after 2 years of use. These responses were seen, to a milder extent in other crops, but our trial elicited heavy symptoms early in treatment. After working with the company, it was determined that these early and severe symptoms were related to soil type (sandy), and watering practices (deficit irrigation). We saw similar results (efficacy) in Mattawa but did not see the same level of phytotoxicity as in the Horse Heaven Hills. That makes sense, as the Mattawa site is on fully irrigated Riesling. We are now moving forward with additional timing trials for Salibro.

Nimitz, unfortunately, did not perform well in either trial. However, at the end of this funding period, we learned (from the company) that the suspected mode of action was against nematode eggs (an ovicide). The currently labeled application timing (spring) does NOT coincide with egg production of *M. hapla*. We are now also completing timing trials with Nimitz to evaluate its efficacy, when applied at a time that would put it in contact with *M. hapla* eggs.

In all years, and at all sites, the use of post-plant nematicides did not influence vine pruning weights, yield, or fruit quality. These attributes will likely take multiple years (5 to 10) before these types of effects, as a result in reduce nematode populations, are seen, if they are seen at all. We are concerned that the timing of post-plant nematicide applications, which typically occur after nematode populations have peaked, and vines are already displaying decline symptoms, may be the current reason why general efficacy of these approaches are low.

Outreach and Education Efforts - Presentations of Research:

As with all our past projects, we have an extensive network of venues and opportunities we continuously engage in order to ensure information is readily accessible to the two stakeholder groups we serve: the scientific community and the industry. We do this through multiple venues including field days, grower meetings, extension publications, and peer-reviewed publications. A list of our communication efforts for this project is below.

Scientific Journals:

- East, K.E., I.A. Zasada, and M.M. Moyer. Field Performance of Wine Grape Rootstocks and Fumigation During Establishment Phase in Washington Vineyards. Am. J. Enol. Vitic. *Submitted 5/1/2020; in review.*
- East, K.E., M.M. Moyer, N. Madden and I.A. Zasada. 2019. How Low Can They Go? Plant-parasitic Nematodes in a Washington Vineyard. Catalyst: Discovery into Practice. 3: 31-36.
- East, K.E., M.M. Moyer, I.A. Zasada, and R.P. Schreiner. 2019. Developmental Dynamics of *Meloidogyne hapla* in Washington Wine Grapes. Plant Dis. 103:966-971. DOI: 10.1094/PDIS-07-18-1195-RE
- Zasada, I.A., A. Howland, A. Peetz, K. East, and M. Moyer. 2019. *Vitis* spp. Rootstocks are Poor Hosts for *Meloidogyne hapla*, a Nematode Commonly Found in Washington Wine Grape Vineyards. Am. J. Enol. Vit. 70: 1-8. DOI: 10.5344/ajev.2018.18027

Presentations and Abstracts:

- Moyer, M.M. " Phylloxera and Rootstocks." 11 Jun 2020. Washington Wine The Group. ZOOM Webinar. 65 attendees.
- Moyer, M.M. "Nematodes and Rootstocks: A Washington Story." 1 Apr 2020. Washington State Wine Commission WAVE Meeting. Webinar. 100 attendees.
- Moyer, M.M. "Rootstocks: The Viticulture Perspective." 4 Mar 2020. Washington Winegrowers 2020 Convention. Kennewick, WA USA. *Invited presentation.*
- Moyer, M.M. "Replanting Right: Vineyard Longevity and Mistakes to Avoid." 4 Mar 2020. Washington Winegrowers 2020 Convention. Kennewick, WA USA. *Invited presentation.*
- Moyer, M.M. "Viticulture Extension and Applied Research in Washington State." 20 Feb 2019. EJ Gallo Winery- Company Seminar Series. Modesto, CA, USA.
- Moyer, M.M. "Rootstocks and Replant Considerations for Nematode Management." 21 Feb 2019. EJ Gallo Winery Annual Grower Meeting – North Valley. Lodi, CA USA. *Invited Presentation.*
- Moyer, M.M. "Rootstocks and Replant Considerations for Nematode Management." 19 Feb 2019. EJ Gallo Winery Annual Grower Meeting – South Valley. Selma, CA USA. *Invited Presentation.*
- Moyer, M.M. "Mildew, Mealybugs, Nematodes and Leaffolders – Local Monitoring for 2018." 11 Apr 2018. Red Mountain Grower Group. Benton City, WA USA. *Invited Presentation.*
- East, K., I. Zasada, R. P. Schreiner, and M. Moyer. 2018. Developmental Dynamics of the Northern Root-Knot Nematode (*Meloidogyne hapla)* in Washington State Vineyards. International Congress for Plant Pathology. Boston, MA, USA.
- East, K. "Managing Nematodes in Vineyards". 15 Nov 2018. Washington State Grape Society Annual Meeting. Grandview, WA
- East, K. "Washington State Viticulture Field Day 2018." 10 August 2018. Washington State Grape Society and WSU Viticulture Extension co-hosts. Sunnyside, WA, USA.
- East, K and M. Moyer. "Nematode Education Stations: Videos, Demoboxes, and Sampling Games." 6 Feb 2018. Washington Winegrowers Association Annual Meeting. Kennewick, WA USA.
- Zasada, I. 2018. Biology and Management of Plant-Parasitic Nematodes. Napa Viticulture Working Group. 10 Jan 2018.
- East, K. 2018. Nematodes 101. GS Long Grower Meeting. 17 Jan 2018. Yakima, WA.
- Zasada, I. 2017. Management Ideas for Plant Parasitic Nematodes in Juice and Wine Grapes. 17 Nov 2017. Washington State Grape Society, Grandview, WA

Posters and Abstracts:

- Moyer, M.M., East, K^{+}., and I. Zasada. 3 Mar 2020. "Rootstocks for Nematode Management in a Vineyard Replant Scenario – An Update." Poster. Washington Winegrowers Association Annual Meeting. Kennewick, WA, USA. (*Award: 1st Professional*).
- Moyer, M., K. East, and I. Zasada. 2019. Effect of Rootstock and Preplant Fumigation on Plant Parasitic Nematode Development in Washington Wine Grapes (abstr.-poster). page 887. 21st International Meeting of Viticulture G*i*ESCO. 23-28 Jun 2019. Thessaloniki, Greece
- East, K., I. Zasada, and M. Moyer. 2019. Post-Plant Nematicide Timing for Northern Root-Knot Nematode in Washington Wine Grapes (abstr.-poster). page 863. 21st International Meeting of Viticulture G*i*ESCO. 23-28 Jun 2019. Thessaloniki, Greece.
- Moyer, M.M., East, K^{+}., and I. Zasada. 12 Feb 2019. "Duration of Fumigant Efficacy in a Vineyard Replant Scenario – An Update." Poster. Washington Winegrowers Association Annual Meeting. Kennewick, WA, USA. (*Award: 1st Professional*).
- East, K^{+}., M. Moyer, I. Zasada, and N.M. Madden. 15 Nov 2018. "Spatial Distribution of Two Nematode Species in a Washington Vineyard." Poster. Washington State Grape Society Annual Meeting. Grandview, WA, USA.
- M. Moyer, K. East, and I.A. Zasada. 2018. Rootstocks in Washington State Winegrape Vineyards: Effects on Plant-Parasitic Nematodes and Vineyard Establishment. International Congress for Plant Pathology. Boston, MA, USA. August 2019.
- Moyer, M.M., K. East, I. Zasada, and P. Schreiner. 6 Feb 2018. "Evaluating Nematode-Resistant Wine Grape Rootstocks in Washington Vineyards." Poster. Poster. Washington Winegrowers Annual Convention. Kennewick, WA, USA. *(Award: 3rd Professional).*
- Zasada, I. 30 Nov 2017. "ARS Nematology Research in Wine Grapes." Poster. USDA/ARS-Grape Industry Research Workshop, Portland, OR.
- Zasada, I., M. Moyer, and K. East. 2018. In-field Evaluation of Grape Rootstock Performance Against Plant Parasitic Nematodes *Meloidogyne hapla* and *Xiphinema* spp. in Washington State. (abstr.-poster). Journal of Nematology 50:665.
- East, K., I. Zasada, and M. Moyer. 16 Nov 2017. "Developmental Dynamics of the Northern Root-knot Nematode *Meloidogyne hapla* in Washington State Vineyards." Poster. Washington State Grape Society Annual Meeting. Grandview, WA

- Moyer, M.M., K. East, I. Zasada, and P. Schreiner. 16 Nov 2017. “Evaluating Nematode-Resistant Wine Grape Rootstocks in Washington Vineyards.” Poster. Washington State Grape Society Annual Meeting. Grandview, WA, USA

Extension Publications:

- Fall 2018 VEEN Article: Northern Root-Knot Nematode in WA Vineyards.” See: http://wine.wsu.edu/extension/viticulture-enology-news-veen/
- Hoheisel, G.A., and M.M. Moyer (eds). Updated Annually. Pest Management Guide for Grapes in Washington. WSU Extension #EB0762. Pullman, WA, USA. 68 pp. (Zasada is the author of the nematode section).

Other Media:

- “WAVE Minute: Exciting Developments in Nematode Research”. 27 Sept 2019. Washington Ag Network Radio Show and Webcast. Developed in partnership with the Washington State Grape and Wine Research Program.

Research Success Statements:

Through the efforts in this project, we have learned that vine response to nematode damage is slow – often not exhibiting decline symptoms until 5 years after planting – a time when vineyards should be reaching near full-capacity production. We learned that pre-plant fumigation, an industry standard for reducing nematode populations prior to replanting, is not a long-term solution for nematode reduction; populations will rebuild over time, contributing to slow decline of this perennial crop. We learned that early-establishment deficit irrigation is a larger influencer on vine growth than nematode feeding (in the first two years), but those irrigation practices may compound longer-term reduction in vine vigor in vineyards with early infestations of root-knot nematode. This emphasizes the point that with own-rooted vines, stress mitigation is one of the few tools growers have to extend the lives of their vineyards infested with nematodes. However, the only true long-term (i.e., over the typical lifespan of a productive vineyard; 30 years) solution to prevent productivity and profit loss due to nematodes is the adoption of nematode-resistant rootstocks. We also learned that post-plant nematicides, while promising in concept, will likely not provide a long-term solution for managing nematode infestations in established own-rooted *V. vinifera* blocks. The products need to have a known nematode life stage target in order to effectively time their application, and for true long-term reduction in nematode damage, they may have to be applied at vineyard inception to potentially protect vines from rapid population increases in nematodes. Their efficacy may be limited if their application regime is implemented after the vines host a large nematode population and are already displaying decline symptoms.

Funds Status:

We have requested a no-cost extension of the funds, as our expenditure rates were lower than expect. Dr. Katherine East, who was funded as a post-doctoral researcher in FY19, accepted a faculty Extension position at Michigan State University in mid-2019. In addition, there were surplus funds relating to the budgeting (in early fiscal years), and subsequent expenditures, associated with state funded (10A) budgets (i.e., state-funded benefits). These additional funds will be expended by the end of the no-cost extension and will be used on existing nematode and rootstock projects that are ongoing and related to this project.

Citations:

East KE, Moyer MM, Zasada IA, and Schreiner RP. 2019. Developmental Dynamics of *Meloidogyne hapla* in Washington Wine Grapes. Plant Dis. 103:966-971. DOI: 10.1094/PDIS-07-18-1195-RE

Schreiner RP, Tarara JM, and Smithyman R. 2007. Deficit irrigation promotes arbuscular colonization of fine roots by mycorrhizal fungi in grapevines (*Vitis vinifera* L.) Mycorrhiza 17:551-562.

Seinhorst JW. 1962. Modifications of the elutriation method for extracting nematodes from soil. Nematologica 8:117-128.