New Brunswick Soil & Crop Improvement Association Inc.
2-150 Woodside Lane Fredericton, NB E3C 2R9
Tel: 506-454-1736 Fax: 506-453-1985 www.nbscia.ca

# Demonstrate Bio-fumigants as a Control of Nematode and *Verticillium* in Potatoes and Strawberries C1920-0201-Y4

## Objectives

To evaluate soil sampling and analytical methodologies for nematodes and *Verticillium* sp. to demonstrate the management of bio-fumigant control in potatoes and strawberries.

## Summary

Root Lesion nematodes have an economic impact on potato production that could be in the range of 10% in Atlantic Canada. Root lesion nematodes and *Verticillium* sp. are associated with a major cause of potato yield reduction commonly referred to as Early Dying Complex (PED). Root Lesion nematodes and *Verticillium* sp. singularly and combined have similar negative impacts on a range of crops. When present these pests can also cause significant economic losses in strawberries.

NBSCIA established mustard bio-fumigant cultivars in a field in 2019 prior to potatoes in 2020 to observe the potential as a fumigant to reduce Root Lesion nematodes and *Verticillium* populations. Similar treatments were established at two locations in 2020 preceding potatoes and one location preceding strawberries. The effectiveness of chemical fumigation was observed in a single location in strawberries in 2021 and 2022. Canadian Forage Pearl Millet was added as a potential biofumigant crop in 2021.

The objective of this project is to evaluate soil sampling and analytical methodologies for nematodes and *Verticillium* sp. to demonstrate the management of bio fumigant control in potatoes and strawberries.

On average, Root Lesion nematode populations increased from spring to fall in each of 2019 and 2020 in the HW potato field and the CM strawberry field in 2020 under the mustard bio-fumigant. Root Lesion nematode populations were significantly reduced from the fall of 2019 to the spring of 2020 at the original HW location. Root Lesion populations were reduced under oats and mustard in the Home 8 field in 2020, however there was little observed difference between the two crop species. Treatment effects were less conclusive in 2021, possibly impacted by the record setting temperature and rainfall throughout the growing season. Root Lesion nematode populations remained stable throughout 2022. Chemical fumigation with Vapam in the Sunset strawberry field clearly reduced Root Lesion nematode populations in 2020, 2021 and 2022.

V. dahlia increased from an average 6644 cells per gram to 23,721 cells per gram of soil under potatoes at the HW field site in the summer of 2020. Mustard bio-fumigant was observed to reduce V. dahlia population in the potato and strawberry fields during the summer of 2020. Oats as a cover crop did not reduce. The average cells per gram of soil for the three oat sites increased from 7701 to 9866 but decreased from 9866 to 6003 under Caliente mustard. Overall V. dahlia populations increased slightly throughout the 2021 season but increased substantially throughout the 2022 growing season.

Initial soil health sampling data established benchmark procedures for future work.

## Conclusion

Chemical fumigation clearly reduced Root Lesion nematode populations in all years. However, the impact of mustard bio-fumigant crops on Root Lesion nematode populations is less definitive, as populations were reduced under oats and mustard in 2020 and none were reported after potatoes in the fall of 2021. Nematode populations were reduced under both mustard and CFPM in 2021.The extremely dry weather experienced during the growing season of 2020 may have been a factor in reducing the chemical reaction of the bio-fumigant or nematodes may have remained below the layer of incorporation of the mustard foliage. The extremely wet weather experienced during the growing season of 2021 may have impacted results, as nematodes may have moved below the sample depth. Root Lesion nematode populations showed a numeric increase throughout 2022.

Mustard bio-fumigant appeared to be effective in reducing V. dahlia population in the potato and strawberry fields during the summer of 2020. Treatment effects were inconclusive in 2021 and 2022. *Verticillium dahlia* populations increased from spring to fall in 2022 in both potatoes and oats.

Utilizing the same laboratory for nematode and *Verticillium* sp. identification and geo-referenced sampling sites increases the confidence of treatment effects observed over time.  However, given the range of variability observed from year to year and location to location further work is required to validate sampling techniques and the effectiveness of mustard and CFPM as bio-fumigant treatments. The data presented suggests that V. dahlia populations may be capable of rebuilding quickly with a susceptible host, such as potatoes and grain.

Given the variance in data from samples collected for analysis remote imagery may be an effective means of visually quantifying treatment effects within a given season and from season to season.

**Présentation de biofumigants pour le contrôle des Nématodes et du Verticillium dans les pommes de terre et les fraises C1920-0201-Y4**

**Objectifs**

Évaluer les méthodologies d'échantillonnage et d'analyse du sol pour les nématodes et Verticillium sp. afin de démontrer la gestion du contrôle des biofumigants dans les pommes de terre et les fraises.

**Résumé**

Les nématodes des lésions racinaires ont un impact économique sur la production de pommes de terre qui pourrait être de près de 10% dans le Canada atlantique. Les nématodes des lésions racinaires et Verticillium sp. sont associés à une cause majeure de réduction du rendement de la pomme de terre, communément appelée complexe de la mort précoce (PED). Les nématodes des racines et les Verticillium sp., seuls ou combinés, ont des effets négatifs similaires sur près de cultures. Lorsqu'ils sont présents, ces ravageurs peuvent également causer des pertes économiques significatives sur les fraises.

L'AASCNB a établi des cultivars de moutarde biofumigants dans un champ en 2019 avant les pommes de terre en 2020 afin d'observer le potentiel de fumigation pour réduire les populations de nématodes des lésions des racines et de Verticillium. Des traitements similaires ont été mis en place à deux endroits en 2020 avant les pommes de terre et à un endroit avant les fraises. L'efficacité de la fumigation chimique a été observée sur un seul site pour les fraises en 2021 et 2022. Le millet perlé fourrager canadien a été ajouté comme culture biofumigants potentielle en 2021.

En moyenne, les populations de nématodes des racines ont augmenté du printemps à l'automne en 2019 et 2020 dans le champ de pommes de terre HW et le champ de fraises CM en 2020 sous le biofumigant de moutarde. Les populations de nématodes des racines ont été significativement réduites de l'automne 2019 au printemps 2020 sur le site original de HW. Les populations de nématodes des racines ont été réduites sous l'avoine et la moutarde dans le champ Home 8 en 2020, mais peu de différences ont été observées entre les deux espèces de cultures. Les effets du traitement ont été moins concluants en 2021, peut-être en raison des températures et des précipitations record enregistrées tout au long de la saison de croissance. Les populations de nématodes des lésions racinaires sont restées stables tout au long de l'année 2022. La fumigation chimique au Vapam dans la fraiseraie Sunset a clairement réduit les populations de nématodes des racines en 2020, 2021 et 2022.

V. dahlia est passé d'une moyenne de 6 644 cellules par gramme à 23 721 cellules par gramme de sol sous les pommes de terre dans le champ HW au cours de l'été 2020. On a observé que le biofumigant moutarde réduisait la population de V. dahlia dans les champs de pommes de terre et de fraises au cours de l'été 2020. L'avoine en tant que culture de couverture n'a pas réduit la population. La moyenne des cellules par gramme de sol pour les trois sites d'avoine a augmenté de 7701 à 9866 mais a diminué de 9866 à 6003 sous la moutarde Caliente. Dans l'ensemble, les populations de V. dahlia ont légèrement augmenté tout au long de la saison 2021, mais ont augmenté de manière substantielle tout au long de la saison 2022.

Les données initiales d'échantillonnage de la santé du sol ont permis d'établir des procédures de référence pour les travaux futures.

**Conclusion**

La fumigation chimique a clairement réduit les populations de nématodes des racines au cours de toutes les années. Cependant, l'impact des cultures biofumigants de moutarde sur les populations de nématodes des racines est moins certain, car les populations ont été réduites sous l'avoine et la moutarde en 2020 et aucune n'a été signalée après les pommes de terre à l'automne 2021. Les populations de nématodes ont été réduites à la fois sous la moutarde et le CFPM en 2021. Le temps extrêmement sec rencontré pendant la saison de croissance de 2020 peut avoir été un facteur de réduction de la réaction chimique du biofumigant ou les nématodes peuvent être restés en dessous de la couche d'incorporation du feuillage de la moutarde. Le temps extrêmement humide de la saison de croissance 2021 peut avoir eu un impact sur les résultats, car les nématodes peuvent s'être déplacés en dessous de la profondeur de l'échantillon. Les populations de nématodes des lésions racinaires ont montré une augmentation numérique tout au long de 2022.

Le biofumigant à base de moutarde a semblé efficace pour réduire la population de V. dahlia dans les champs de pommes de terre et de fraises au cours de l'été 2020. Les effets du traitement n'ont pas été concluants en 2021 et 2022. Les populations de Verticillium dahlia ont augmenté du printemps à l'automne 2022 dans les champs de pommes de terre et d'avoine.

L'utilisation du même laboratoire pour l'identification des nématodes et de Verticillium sp. et de sites d'échantillonnage géoréférencés augmente la confiance dans les effets du traitement observés au fil du temps. Cependant, étant donné le degré de variabilité observé d'une année à l'autre et d'un endroit à l'autre, des travaux supplémentaires sont nécessaires pour valider les techniques d'échantillonnage et l'efficacité de la moutarde et du CFPM en tant que traitements biofumigants. Les données présentées suggèrent que les populations de V. dahlia peuvent être capables de se reconstituer rapidement avec un hôte sensible, comme les pommes de terre et les céréales.

Compte tenu de la variance des données des échantillons collectés pour l'analyse, l'imagerie à distance peut être un moyen efficace de quantifier visuellement les effets du traitement au cours d'une saison donnée et d'une saison à l'autre.

**Enabling Agricultural Research and Innovation**

**Element 1, Innovative Research and Development Final Report**

1. *Project title and project number*: C1920-0201-Y4 Demonstrate Bio-fumigants as a Control of Nematode and *Verticillium* in Potatoes and Strawberries

2. *Project leader and collaborators*: The project team consists Ray Carmichael, MSc. Ag. and Andrew Sytsma, NBSCIA Club Agrologists. The collaborating farmers are Carpenter Farms Ltd Charles McIntosh, Sunset U-Pick and McCain Farm of the Future.

3. *Summary:* Root Lesion nematodes have an economic impact on potato production that could be in the range of 10% in Atlantic Canada. Root lesion nematodes and *Verticillium* sp. are associated with a major cause of potato yield reduction commonly referred to as Early Dying Complex (PED). Root Lesion nematodes and *Verticillium* sp. singularly and combined have similar negative impacts on a range of crops. When present these pests can also cause significant economic losses in strawberries.

   NBSCIA established mustard bio-fumigant cultivars in a field in 2019 prior to potatoes in 2020 to observe the potential as a fumigant to reduce root lesion nematodes and *Verticillium* populations. Similar treatments were established at two locations in 2020 preceding potatoes and one location preceding strawberries. The effectiveness of chemical fumigation was observed in a single location in strawberries in 2021 and 2022. Canadian Forage Pearl Millet was added as a potential biofumigant crop in 2021.

   The objective of this project is to evaluate soil sampling and analytical methodologies for nematodes and *Verticillium* sp. to demonstrate the management of bio fumigant control in potatoes and strawberries

   On average, Root lesion nematode populations increased from spring to fall in each of 2019 and 2020 in the HW potato field and the CM strawberry field in 2020 under the mustard bio-fumigant. Root lesion nematode populations were significantly reduced from the fall of 2019 to the spring of 2020 at the original HW location. Root lesion populations were reduced under oats and mustard in the Home 8 field in 2020, however there was little observed difference between the two crop species. Treatment effects were less conclusive in 2021, possibly impacted by the record setting temperature and rainfall throughout the growing season. Root lesion nematode populations remained stable throughout 2022. Chemical fumigation with Vapam in the Sunset strawberry field clearly reduced Root lesion nematode populations in 2020, 2021 and 2022.

   V. dahlia increased from an average 6644 cells per gram to 23,721 cells per gram of soil under potatoes at the HW field site in the summer of 2020. Mustard bio-fumigant was observed to reduce V. dahlia population in the potato and strawberry fields during the summer of 2020. Oats as a cover crop did not reduce. The average cells per gram of soil for the three oat sites increased from 7701 to 9866 but decreased from 9866 to 6003 under Caliente mustard. Overall V. dahlia populations increased slightly throughout the 2021 season but increased substantially throughout the 2022 growing season.

   Initial soil health sampling data established benchmark procedures for future work.

4. *Introduction:* There are no statistically validated estimates in Canada of yield losses in potatoes due to nematodes, however in the United States, it is estimated that 10% of the potato crop is lost annually because of nematodes, and it is reasonable to assume that this percentage is also applicable to Canada and the Atlantic region. The most important nematode parasite of potatoes in the northeastern United States and in eastern Canada is the root lesion nematode, Pratylenchus penetrans. Several other root lesion nematode species attack potatoes but are not important or have not been detected in the Atlantic region.

   Since nematodes usually attack underground plant parts, there are no reliable foliar symptoms to signify that nematodes may be the major cause of poor growth and reduced tuber yields in potatoes. In roots, injury by nematodes may be detected by the presence of lesions, cysts or galls. After a few weeks, however, roots are attacked by other pathogens such as bacteria and fungi (*Verticillium* sp.), and the original damage by nematodes may not be obvious. Consequently, nematode damage has often been attributed to other factors. Root lesion nematodes invade and migrate in potato roots, though tubers are sometimes invaded when nematode populations are very high. Root lesion nematodes and *Verticillium* sp. are associated with a major cause of potato yield reduction commonly referred to as Early Dying Complex (PED).

Adult females lay eggs in roots or soil. Second stage juveniles hatch from the eggs, invade roots, and develop through the third and fourth stages to adults. Second, third, and fourth stage juveniles, as well as adult males and females are all capable of invading and migrating through roots. A life cycle takes 20 to 60 days to complete, and depends mostly on the condition of the host and on soil temperature. Maximum damage occurs in sandy soils, since these nematodes prefer this type of soil, and also because sandy soils are suited for potato culture. Above-ground symptoms caused by high populations of root lesion nematodes are sometimes falsely attributed to lack of water or nutrients.

Fumigant nematicides are an expedient way to control nematodes. The major disadvantage of chemical control is the cost of fumigants and the need for specialized equipment. Planting is delayed by three or four weeks if fumigants are applied in the spring. In addition, there is the possibility that residues may be left in tubers or may contaminate groundwater. Soil fumigants also are not discriminating in the organisms they control and may destroy beneficial soil life as well as the target pests.

Mustard is a well understood bio fumigant. Its bio fumigation properties have been studied for a number of years and scientists have developed a method to fully use these properties. Mustard has been shown to control a variety of soil borne pests. These include *Verticillium* spp., *Rhizoctonia* spp., *Fusarium* spp., *Pythium* spp., *Sclerotinia* spp., common scab and a range of nematodes. The use of mustard as a bio fumigant has also shown a decrease in damage caused by wireworm. However, using a bio fumigant non-cash crop results in lost income for the year and significant input costs which can approximate the cost of chemical fumigants.

Compounding the situation is finding crops that complement the potato crop in regards to soil health and disease cycles while providing an economic benefit. Pearl millet also has properties that control root lesion nematodes and can act as a green manure crop to improve soil health in the break years of potato rotations. Pearl millet following a mustard crop could potentially further reduce Root lesion nematodes.

The bio fumigant (mustard) crop must be cut and incorporated into the soil not more than 60 days after planting and before the crop goes to seed. While there is time to establish a second crop the cutting and incorporation will conflict with potato harvest. The use of a millet crop following the mustard crop may eliminate the need to cut and incorporate a second mustard crop during potato harvest while still having an impact on the nematode population.

5. *Project Objective(s):* To evaluate soil sampling and analytical methodologies for nematodes and *Verticillium* sp. to demonstrate the management of bio fumigant control in potatoes and strawberries.

6. *Project Deliverable(s):*
   1. The level of Root lesion nematode and *Verticillium* sp. in the field prior to establishing the bio fumigant crop and levels at seasons end.
   2. Management of the break crop by the producer to control the nematode and virus population in the field, as well as improving soil organic matter and acting as a nutrient sink.
   3. A cost benefit comparison between bio fumigation and chemical fumigation.

7. *Material and Methods*: The initial collaborating producer (Carpenter Farms) indicated that one of their potato fields exhibited poor growth in sections of the field in 2017.Soil samples from a Carpenter Farms' field (HW) in the fall of 2018 identified higher levels of Root Lesion Nematode in sections of the field where the crop production was reduced compared to the "newer" area. Because Potato Early Die (PED) symptoms are not expressed uniformly throughout a field. All soil sample sites were geo-referenced.

   Replicated bio-fumigant treatments of Mighty, Attack and Centennial mustard were established in 2019 in the HW field. Pearl Millet, Sorghum Sudan grass and oats were planted as cover crops following incorporation of the mustard bio fumigant species. Samples from the geo-referenced locations were collected in the spring and fall of 2019, 2020,2022 and fall of 2021

A second field location (Home-8) was identified and six geo-referenced sample sites were established in the fall of 2019.The field was split with Caliente mustard and oats and seeded June 5, 2020. Both crops were chopped, prior to mustard seed formation and incorporated on July 22, 2020. A second crop of each species was replanted on August 27, 2020. Soil samples from the geo-referenced locations were collected in the fall of 2019, spring and fall of 2020, 2021 and 2022 and assessed for nematodes and Verticillum sp.

A third site was established in Home 8 in the spring of 2021 and split to compare Canadian Forage Pearl Millet (CFPM) with Caliente mustard. Three geo-referenced sample sites were located in each crop species. A similar side by side comparison with geo-referenced sample sites was established in a second field site CampMid. Samples were collected from each field location in the spring and fall of 2021and 2022 and assessed for nematodes and Verticillum sp.

Biomass imagery from Climate Fieldview was monitored throughout the 2021 season to identify potential visual symptoms of PED for Carpenter Home 8 and HW fields.

Spring and fall samples for nematode and *Verticillium* sp. identification were collected from two strawberry farm sites identified in 2020. As a comparison one of the strawberry farm cooperators has a history of chemical fumigation and one field site was treated with a chemical fumigant in 2020, 2021 and 2022.

Experience from the initial work in 2019 identified variance between laboratory methodologies and interpretation of results regarding critical levels for both nematodes and *Verticillium* sp. To eliminate this variance all nematode evaluations were conducted by the University of Guelph, Agriculture and Food Laboratory and soil scans using qPCR technology for DNA identification of *Verticillium* sp. were undertaken at Agricultural Certification Service.

With *Verticillium* qPCR testing, the level of *Verticillium* species in soil is quantified directly by the extractable DNA from soil samples. For practical purposes, this is converted into an estimate of the number of cells per gram of soil based upon the known DNA content of *Verticillium dahliae*. The quantity of *Verticillium* DNA as reported is not atypically very high or low compared to representative *Verticillium*-positive samples in New Brunswick potato rotations. How these DNA concentrations relate to infection risk, symptom expression and possible yield reduction in the field, however, likely depends on many factors.

A series of greenhouse experiments recently completed by Agricultural Certification Services determined that tuber yield of greenhouse-grown Russet Burbank potato plants was reduced by 50% at V. dahliae inoculum levels of 0.035 ng/g soil, compared to control plants not exposed to V. dahliae in the soil; this increased to 75% reduction in tuber yield at 0.123 ng/g soil. Given that the values recorded lay close to the conditions of the ACS greenhouse experiment, the potential for substantial infection and yield reduction exists.

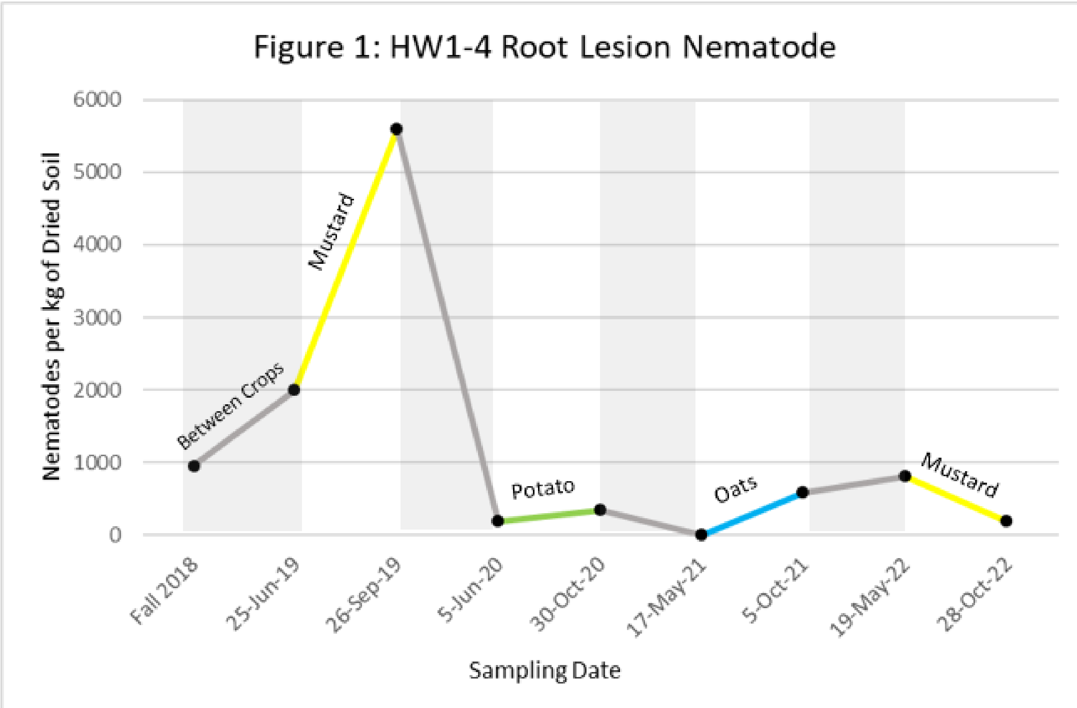
The ACS experiment did not determine a safe lower limit of *Verticillium* DNA that does not cause tuber yield reduction compared to the control. Literature values of *Verticillium* DNA levels in soil corresponding to crop outcomes are rare for potatoes, but in other susceptible crops, DNA levels as low as 0.003 ng/g soil can cause detectable levels of plant infection. The DNA levels (ng/g of soil) reported for all samples are in excess of the suggested low limit of 0.003ng/g.

A number of samples for soil health analysis were collected in 2021 from selected geo-referenced sites across all field locations for observation of potential correlation between soil health parameters and nematode and *Verticillium* sp. occurrence. Basic soil health analysis were conducted by PEI Analytical Laboratories

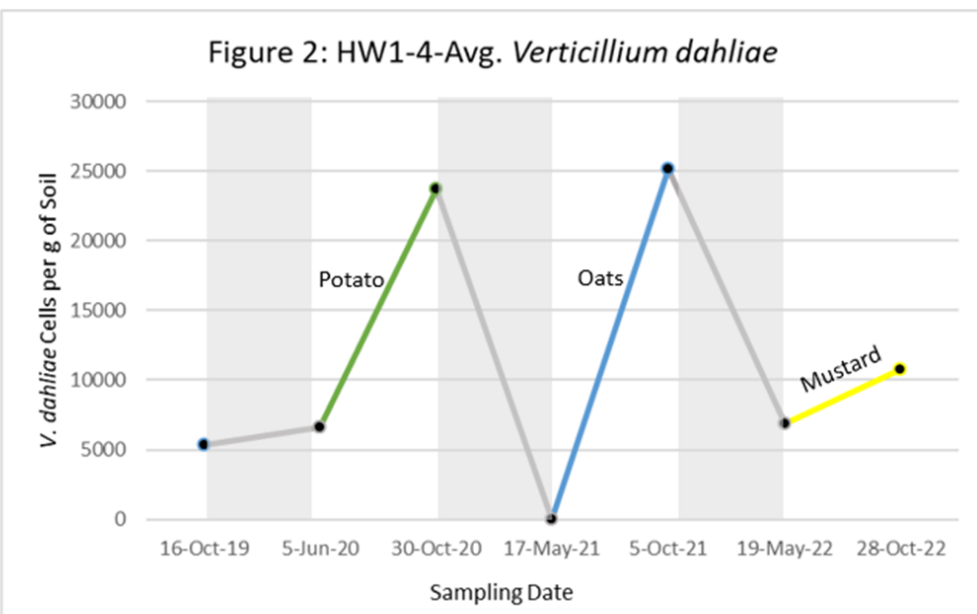
The cost of a typical biofumigant treatment was estimated using an excel spreadsheet and the equipment investment and typical work rates for Carpenter Farms.

8. *Results and Discussion*:

Fall sample results for 2021 for nematode and *Verticillium* sp. for the Carpenter HW field with all historical values are presented in Figures 1 and 2 below:

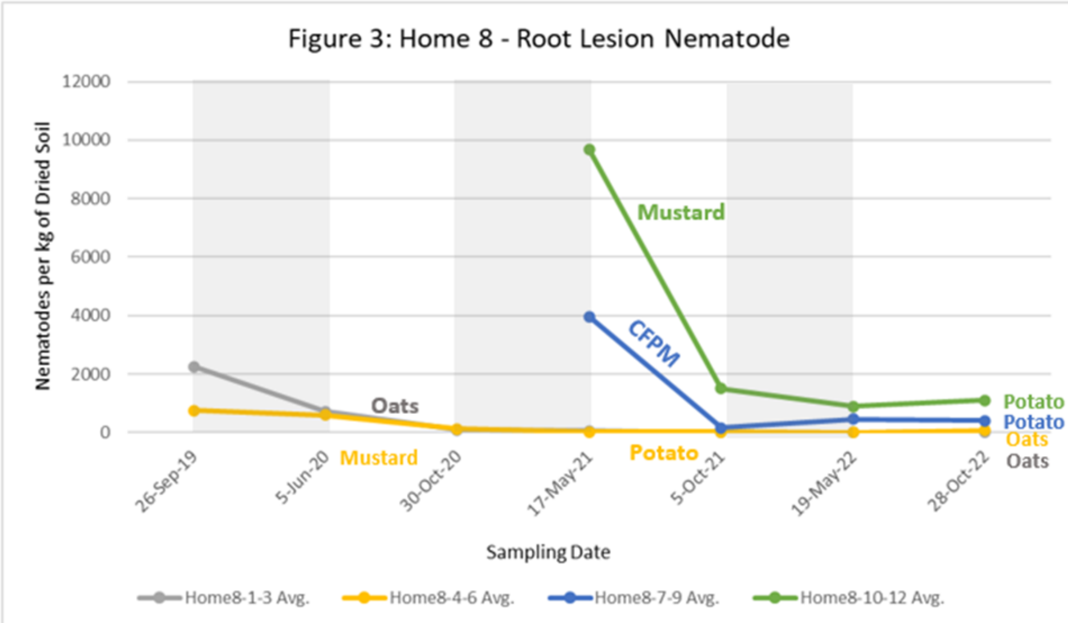



Root-lesion population as reported were depressed in the spring of 2020 prior to the potato crop and subsequent to the biofumigant treatments of 2019. Populations increased slightly during 2020 with potatoes and again in 2021 under the oat crop. However, they were considerably lower than the levels reported throughout the 2019 crop season.



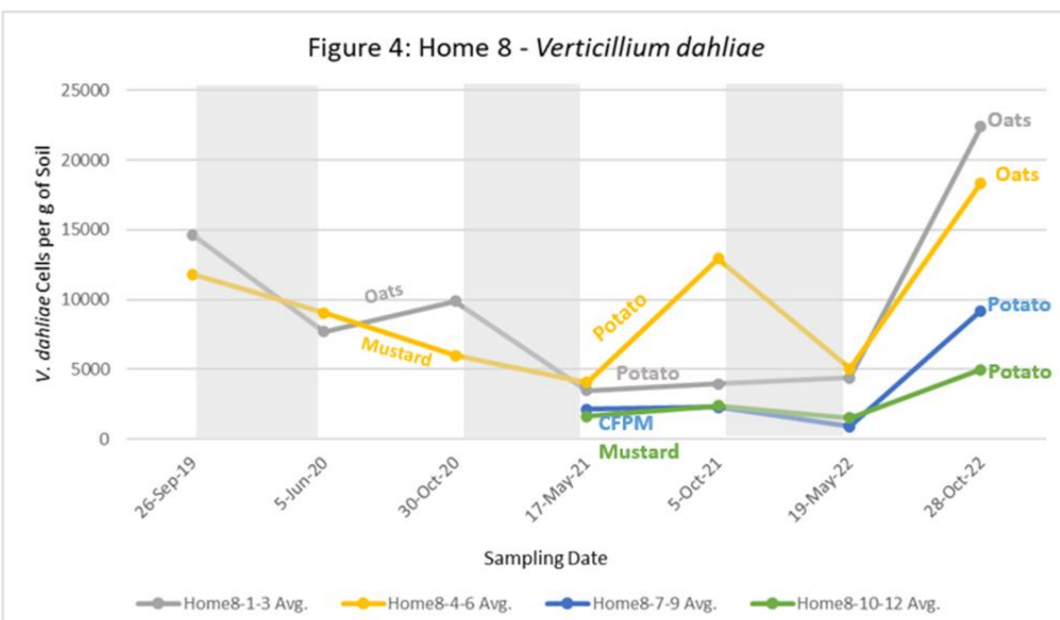

The number of *Verticillium dahliae* cells per gram of soil were observed to be similar between the fall of 2019 and the spring of 2020 but exhibited a large increase during the 2020 growing season and increased again in 2021 under oats. Suggesting that V dahlia populations may be capable of rebuilding quickly with a susceptible host such as potatoes.

Spring and fall nematode populations for 2019, 2020, 2021 and 2022 for Carpenter field 8 sites are presented in Figure 3, below.



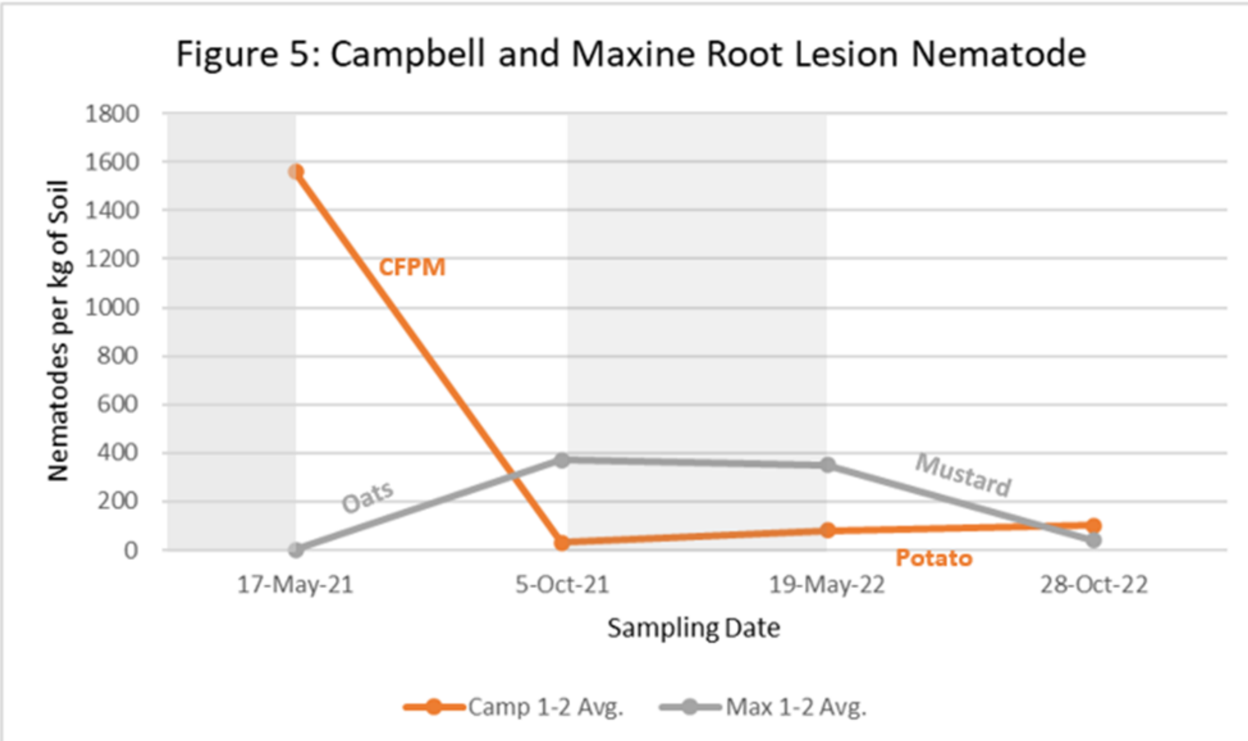

In the fall of 2021 Root-lesion nematode counts were 0 for the three sample sites with oats in 2020 compared to Caliente mustard with 20 nematodes per kg of soil in the fall of 2021 following potatoes. On average the three sample sites treated with Canadian Forage Pearl Millet demonstrated a greater reduction in Root-lesion nematode counts per kg of soil than the three sites with Caliente mustard in the fall of 2021 and 2022 following potatoes.

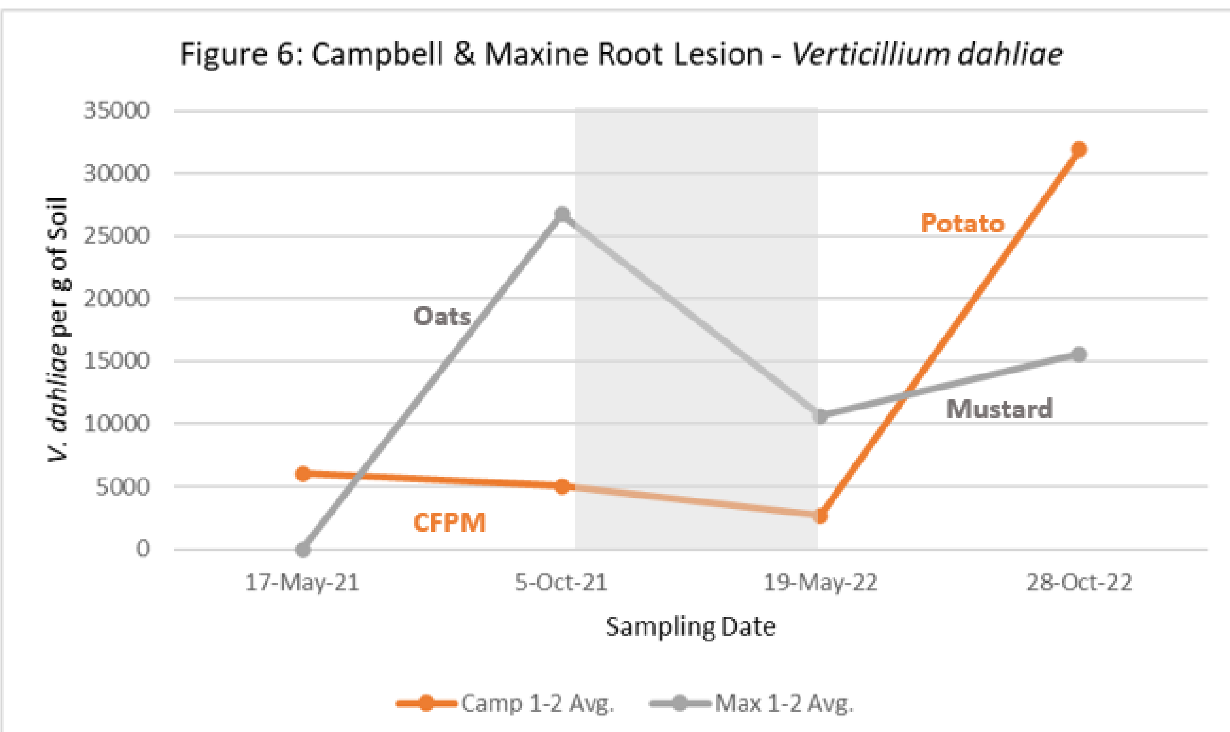
Spring and fall *Verticillium dahlia* cells per gram of soil for 2019, 2020, 2021 and 2022 for all Carpenter field eight are presented in Figure 4, below.




Mustard bio-fumigant was observed to reduce V. dahlia population during the summer of 2020, following potatoes in 2019. Oats as a cover crop did not reduce V. dahlia. The average cells per gram of soil for the three oat sites in the field Home 8-1, 2, and 3 increased from 7701 to 9866 under oats but decreased from 9866 to 6003 under Caliente mustard (Sites 4, 5 and 6). *Verticillium* dahliae concentrations increased in each treatment with potatoes in 2021, and continued to increase in 2022 with oats.

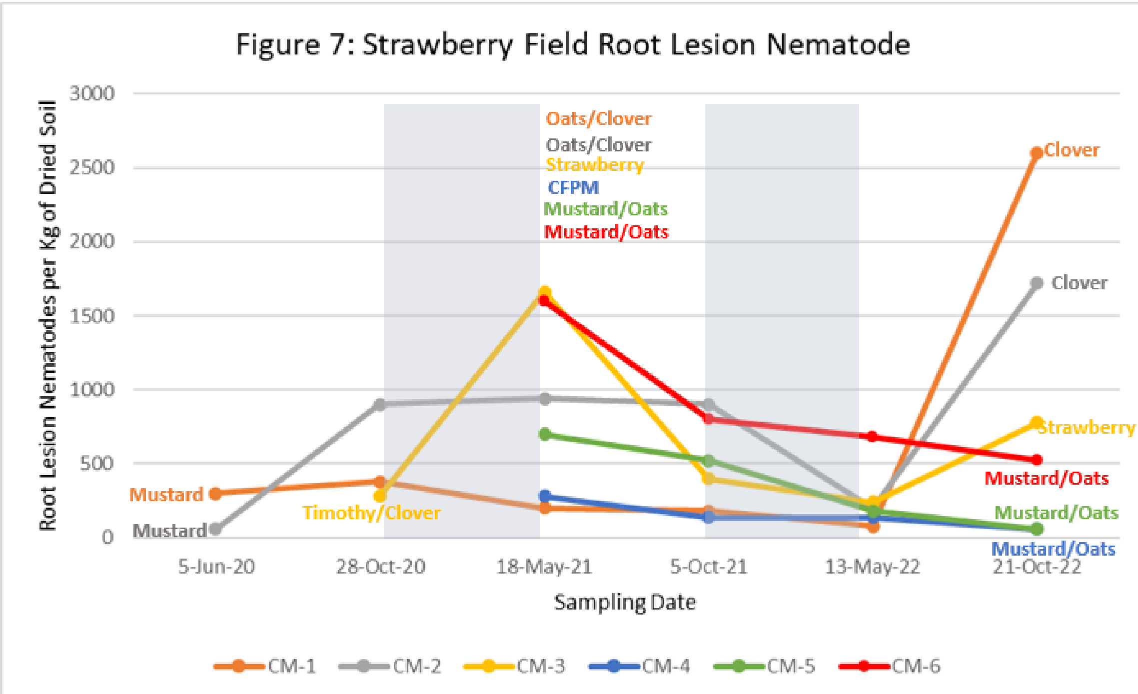
Two additional field sites were established at Carpenter Farms to observe the biofumigant effect of Canadian Forage Pearl Millet (CFPM) on Root lesion nematodes and *V. dahlia* as reported in Figures 5 and 6 below.



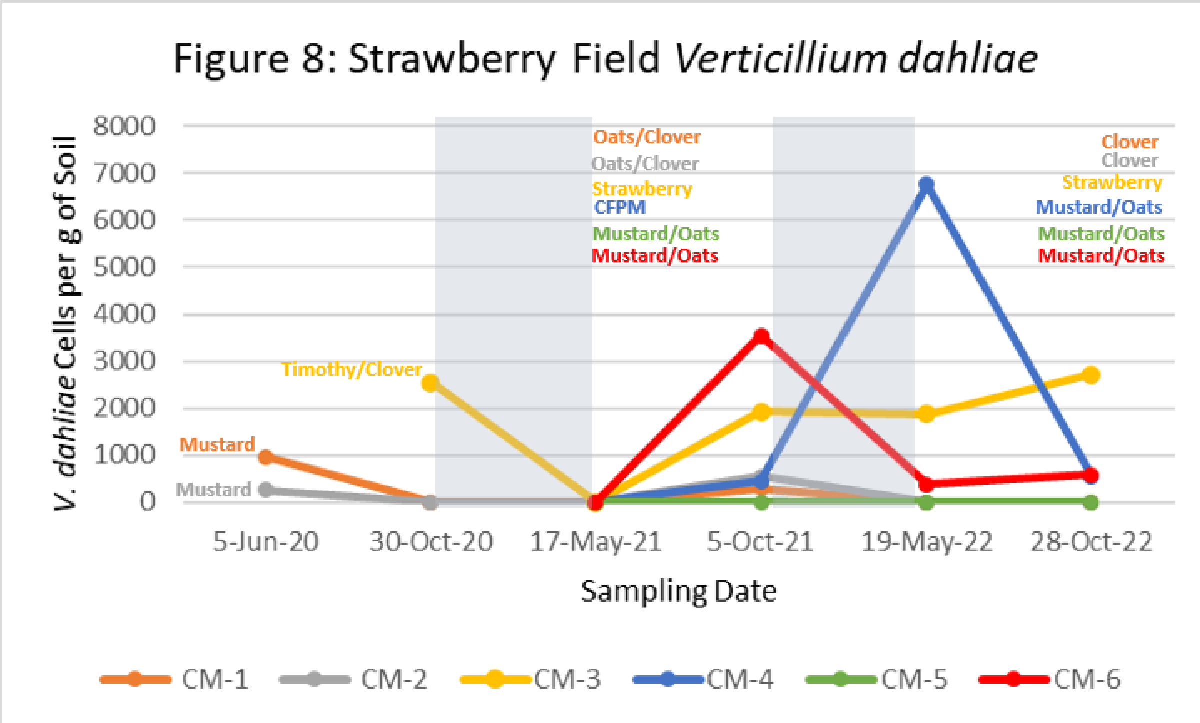



Canadian Forage Pearl Millet was observed to provide a greater reduction in Root lesion nematodes and V. dahlia compared to oats.

Nematode populations for 2020, 2021and 2022 in a strawberry field site are reported in Figure 7 (below). The Root-lesion populations for the CM biofumigant samples sites are inconclusive and variable, demonstrating no real trend. Chemical fumigation clearly reduced Root lesion nematode populations in the strawberry fields in 2020, 2021 and 2022.




*Verticillium* sp concentrations for 2020 and 2021 in strawberry field sites are reported in Figure 8, below. A very low level of *Verticillium dahliae* was reported in one sample site in the fall 2020. No *Verticillium dahliae* was reported in the spring of 2021 but with a slight increase in the fall of 2021 and variable results throughout 2022.




Soil health, *Verticillium* sp and Root-lesion nematodes results, were previously reported in 2021 (C1920-0201-Y3 Demonstrate Bio-fumigants as a Control of Nematode and *Verticillium* in Potatoes and Strawberries). This is a very preliminary look at potential relationships between soil health parameters and the occurrence of *Verticillium* and Root-lesion nematodes, as such it is impossible to draw any conclusions. It is worth noting that two parameters related to soil biological activity, Respiration and Biological Nitrogen Activity, showed slight increase during the growing season.

All observed variance from both farms is considered to be within the limits of random error due to timing, sample location and without replication, can not be attributed to treatment effects. Given the variability observed, other methods may be effective tools to define the effectiveness of biofumigant within a year and between years. The exact sample locations and biomass ratings from Climate Fieldview are illustrated in Appendix Figures 1.

Using the equipment investment and typical work rates for Carpenter Farms, an estimate of the cost of bio fumigation was calculated to serve as a reference for chemical fumigation costs (Table 1, below). The estimated cost for a mustard biofumigant treatment is $389 per acre.

| TABLE 1: PARTIAL BIOFUMIGANT BUDGET | | | |
|---|---|---|---|
| | | | |
| CROP INCOME: | | | $0.00 |
| | | | |
| CROP EXPENSE: | | | COST/Ac. |
| Seed | | | $74.00 |
| Fertilizer | | | $48.75 |
| Lime | | | $0.00 |
| Pesticides | | | $0.00 |
| Labor | | | $0.00 |
| Crop Insurance | | | $0.00 |
| Miscellaneous | | | $0.00 |
| Operating Interest | | | $0.00 |
| Land | | | $0.00 |
| CROP INPUT EXPENSE TOTAL | | | $122.75 |
| | | | |
| MACHINE OPERATION: | | | |
| # TIMES | DESCRIPTION | | COST/Ac. |
| 2 | Plowing | | $63.52 |
| 3 | Harrowing | | $40.82 |
| 1 | Fertilizing | | $9.42 |
| 2 | Seeding | | $29.81 |
| 1 | Flailing | | $30.66 |
| 1 | Packing | | $31.76 |
| 1 | Seed Truck | | $60.20 |
| MACHINE OPERATION TOTAL | | | $266.18 |
| | TOTAL: | | $388.93 |

9. *Conclusions*:

Chemical fumigation clearly reduced Root lesion nematode populations in all years. However, the impact of mustard bio-fumigant crops on Root lesion nematode populations is less definitive, as populations were reduced under oats and mustard in 2020 and none were reported after potatoes in the fall of 2021. Nematode populations were reduced under both mustard and CFPM in 2021.The extremely dry weather experienced during the growing season of 2020 may have been a factor in reducing the chemical reaction of the bio-fumigant or nematodes may have remained below the layer of incorporation of the mustard foliage. The extremely wet weather experienced during the growing season of 2021 may have impacted results, as nematodes may have moved below the sample depth. Root lesion nematode populations showed a numeric increase throughout 2022.

Mustard bio-fumigant appeared to be effective in reducing V. dahlia population in the potato and strawberry fields during the summer of 2020. Treatment effects were inconclusive in 2021 and 2022. *Verticillium dahlia* populations increased from spring to fall in 2022 in both potatoes and oats.

Utilizing the same laboratory for nematode and *Verticillium* sp. identification and geo-referenced sampling sites increases the confidence of treatment effects observed over time.  However, given the range of variability observed from year to year and location to location further work is required to validate sampling techniques and the effectiveness of mustard and CFPM as bio-fumigant treatments. The data presented suggests that V dahlia populations may be capable of rebuilding quickly with a susceptible host, such as potatoes and grain.

Given the variance in data from samples collected for analysis remote imagery may be an effective means of visually quantifying treatment effects within a given season and from season to season.

10. *Required next steps*:

Further testing at multiple sites is required to compare the efficacy and cost of crop bio fumigant treatments with registered chemical treatment such as Chloropicrin, Veleum Prime and Elatus to control nematode and *Verticillium* species.

These data collected should also be supported with Soil Health Analysis for any correlation with Soil OM, Respiration, Biological Nitrogen Availability and soil texture.

11. *Communication:*
The data generated by this project will be analyzed and reported in the NBSCIA annual report and used at producer meetings, and local association meetings when requested.

12. *Intellectual Property:*
There are no intellectual properties involved with this project.

# Appendix Tables

**Appendix Table 1: Carpenter Farms Number of Root Lesion Nematodes/kg of Dried Soil**

| | Fall 2018 | | 25-Jun-19 | 26-Sep-19 | | 5-Jun-20 | 30-Oct-20 | | 17-May-21 | 5-Oct-21 | | 19-May-22 | 28-Oct-22 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot | Root-lesion | Treatment 2019 Crop | Root-lesion | Root-lesion | 2020 Crop | Root-lesion | Root-lesion | 2021 Crop | Root-lesion | Root-lesion | 2022 Crop | Root-lesion | Root-lesion |
| HW-1 | 1440 | Mustard | 1800 | 12341 | Potato | 40 | 520 | Oats | | 340 | Mustard | 1780 | 440 |
| HW-2(new) | 420 | Mustard | 1768 | 1549 | Potato | 260 | 560 | Oats | | 1300 | Mustard | 400 | 120 |
| HW-3 | 980 | Mustard | 3143 | 3990 | Potato | 200 | 100 | Oats | | 300 | Mustard | 820 | 140 |
| HW-4 | 980 | Mustard | 1261 | 4494 | Potato | 220 | 180 | Oats | | 360 | Mustard | 200 | 20 |
| **Average** | **955** | **Mustard** | **1993** | **5594** | **Potato** | **180** | **340** | **Oats** | | **575** | **Mustard** | **800** | **180** |
| Home 8-1 | | | | 3680 | Oat | 760 | 0 | Potato | 80 | 0 | Oat | 0 | 0 |
| Home 8-2 | | | | 1680 | Oat | 1220 | 160 | Potato | 40 | 0 | Oat | 0 | 20 |
| Home 8-3 | | | | 1400 | Oat | 200 | 140 | potato | 60 | 0 | Oat | 0 | 60 |
| **Average** | | | | **2253** | **Oats** | **727** | **100** | **Potato** | **60** | **0** | **Oats** | **0** | **27** |
| Home 8-4 | | | | 500 | Mustard | 1060 | 60 | Potato | 20 | 0 | Oat | 0 | 0 |
| Home 8-5 | | | | 1340 | Mustard | 240 | 240 | Potato | 20 | 0 | Oat | 40 | 20 |
| Home 8-6 | | | | 440 | Mustard | 520 | 80 | Potato | 20 | 60 | Oat | 0 | 180 |
| **Average** | | | | **760** | **Mustard** | **607** | **127** | **Potato** | **20** | **20** | **Oats** | **13** | **67** |
| Home 8-7 | | | | | | | | CFPM | 4360 | 80 | Potato | 600 | 300 |
| Home 8-8 | | | | | | | | CFPM | 5120 | 280 | Potato | 340 | 600 |
| Home 8-9 | | | | | | | | CFPM | 2400 | 140 | Potato | 440 | 300 |
| **Average** | | | | | | | | **CFPM** | **3960** | **167** | **Potato** | **460** | **400** |
| Home 8-10 | | | | | | | | Mustard | 10400 | 2480 | Potato | 1140 | 1500 |
| Home 8-11 | | | | | | | | Mustard | 2680 | 960 | Potato | 460 | 460 |
| Home 8-12 | | | | | | | | Mustard | 16000 | 1060 | Potato | 1060 | 1360 |
| **Average** | | | | | | | | **Mustard** | **9693** | **1500** | **Potato** | **887** | **1107** |
| Camp.Med 1 | | | | | | | | CFPM | 2560 | 20 | Potato | 20 | 60 |
| Camp.Med 2 | | | | | | | | CFPM | 560 | 40 | Potato | 140 | 140 |
| **Average** | | | | | | | | **CFPM** | **1560** | **30** | **Potato** | **80** | **100** |
| Max-1 | | | | | | | | Oats | | 620 | Mustard | 80 | 40 |
| Max-2 | | | | | | | | Oats | | 120 | Mustard | 620 | 40 |
| **Average:** | | | | | | | | **Oats** | | **370** | **Mustard** | **350** | **40** |

**Appendix Table 2: Carpenter Farms V. dahliae (cells per g of soil estimate based on known DNA size of V. dahliae genome = 36.5 fg/cell)**

| | 25-Jun-19 | 16-Oct-19 | 2020 Crop | 5-Jun-20 | 30-Oct-20 | 2021 Crop | 17-May-21 | 5-Oct-21 | 2022 Crop | 19-May-22 | 28-Oct-22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HW-1 | na | 9030 | Potato | 7199 | 16767 | Oats | na | 18283 | Mustard | 2801 | 6629 |
| HW-2 | na | 4434 | Potato | 2310 | 5226 | Oats | na | 29022 | Mustard | 12774 | 14275 |
| HW-3 | na | 5201 | Potato | 7121 | 52599 | Oats | na | 26496 | Mustard | 5916 | 10599 |
| HW-4 | na | 2842 | Potato | 9948 | 20293 | Oats | na | 26852 | Mustard | 5995 | 11680 |
| **Average:** | | **5377** | **Potato** | **6645** | **23721** | **Oats** | | **25164** | **Mustard** | **6871** | **10796** |
| Home 8-1 | | 8776 | Oat | 6293 | 11616 | Potato | 3097 | 4958 | Oat | 5602 | 22990 |
| Home 8-2 | | 25494 | Oat | 6621 | 7746 | Potato | 2429 | 4027 | Oat | 3536 | 22953 |
| Home 8-3 | | 9636 | Oat | 10190 | 10237 | potato | 4884 | 2917 | Oat | 4053 | 21144 |
| **Average:** | | **14635** | **Oats** | **7701** | **9866** | **Potato** | **3470** | **3967** | **Oats** | **4397** | **22362** |
| Home 8-4 | | 11624 | Mustard | 7890 | 5868 | Potato | 3326 | 18610 | Oat | 5584 | 16378 |
| Home 8-5 | | 12937 | Mustard | 8067 | 7029 | Potato | 5050 | 11682 | Oat | 4253 | 21016 |
| Home 8-6 | | 10841 | Mustard | 11165 | 5112 | Potato | 3780 | 8460 | Oat | 5330 | 17640 |
| **Average:** | | **11801** | **Mustard** | **9041** | **6003** | **Potato** | **4052** | **12918** | **Oats** | **5056** | **18345** |
| Home 8-7 | | | | | | CFPM | 3105 | 1848 | Potato | 2659 | 9978 |
| Home 8-8 | | | | | | CFPM | 1424 | 2834 | Potato | 0 | 2632 |
| Home 8-9 | | | | | | CFPM | 1885 | 2129 | Potato | 0 | 14902 |
| **Average:** | | | | | | **CFPM** | **2138** | **2270** | **Potato** | **886** | **9171** |
| Home 8-10 | | | | | | Mustard | 3089 | 1249 | Potato | 1273 | 4871 |
| Home 8-11 | | | | | | Mustard | 981 | 2671 | Potato | 1602 | 6578 |
| Home 8-12 | | | | | | Mustard | 764 | 3212 | Potato | 1639 | 3404 |
| **Average:** | | | | | | **Mustard** | **1611** | **2377** | **Potato** | **1505** | **4951** |
| Camp.Med 1 | | | | | | CFPM | 4497 | 4436 | Potato | 2493 | 5363 |
| Camp.Med 2 | | | | | | CFPM | 7524 | 5654 | Potato | 2895 | 58401 |
| **Average:** | | | | | | **CFPM** | **6011** | **5045** | **Potato** | **2694** | **31882** |
| Max-1 | | | | | | Oats | | 40988 | Mustard | 14145 | 13555 |
| Max-2 | | | | | | Oats | | 12454 | Mustard | 7149 | 17629 |
| **Average:** | | | | | | **Oats** | | **26721** | **Mustard** | **10647** | **15592** |

## Appendix Table 3: Strawberry Fields Nematodes/kg of Dried Soil

| Field | Crop | June 5,2020 Root-lesion | June 5,2020 Spiral | June 5,2020 Pin | Oct 30,2020 Root-lesion | Oct 30,2020 Pin | Oct 30,2020 Knot |
|---|---|---|---|---|---|---|---|
| CM-1 | Caliente | 300 | 0 | 0 | 380 | 0 | 0 |
| CM-2 | Pacific Gold | 60 | 0 | 0 | 900 | 0 | 0 |
| CM-3 | Timothy-Clover | na | na | na | 280 | 4380 | 0 |
| CM-4 | | | | | | | |
| CM-5 | | | | | | | |
| CM-6 | | | | | | | |
| Jordie | Strawberry | na | na | na | 600 | 0 | 520 |
| Blueberry field | Strawberry | na | na | na | 80 | 0 | 0 |
| Wrong Way | Strawberry | na | na | na | 20 | 0 | 0 |
| Hill | Strawberry | na | na | na | 640 | 0 | 60 |
| | | PreFumigant | | | PostFumigant | | |
| Blueberry | Strawberry | 140 | 0 | 60 | 20 | 0 | 0 |

| Field | Crop | May 17,2021 Root-lesion | May 17,2021 Pin | May 17,2021 Knot | Oct 4,2021 Root-lesion | Oct 4,2021 Pin | Oct 4,2021 Knot |
|---|---|---|---|---|---|---|---|
| CM-1 | Oats/clover | 200 | 0 | | 180 | 160 | |
| CM-2 | Oats/clover | 940 | 0 | | 900 | 20 | |
| CM-3 | Strawberry | 1660 | 1460 | | 400 | 1280 | |
| CM-4 | CFPM | 280 | 0 | | 140 | 80 | |
| CM-5 | Mustard/oats | 700 | 0 | | 520 | 0 | |
| CM-6 | Mustard/oats | 1600 | 20 | | 800 | 140 | |
| Field | Crop | Oct 26,2021 -PreFumigant | | | Nov 15,2021-PostFumigant | | |
| Beside Hill | | 1200 | 20 | 60(Dagger) | 40 | | 20 |
| By SprayTank | | 120 | | 180(Knot) | 20 | 0 | 0 |
| Raspberry | | 180 | | | 220 | 0 | 0 |

| Field | 1-Jun-22 Root-lesion | 1-Jun-22 Spiral | 1-Jun-22 Pin | 28-Nov-22 Root-lesion | 28-Nov-22 Spiral | 28-Nov-22 Pin |
|---|---|---|---|---|---|---|
| CM-1 | 80 | 0 | 20 | 2600 | 0 | 20 |
| CM-2 | 200 | 0 | 0 | 1720 | 0 | 240 |
| CM-3 | 240 | 40 | 1260 | 780 | 0 | 360 |
| CM-4 | 140 | 0 | 20 | 60 | 0 | 20 |
| CM-5 | 180 | 0 | 0 | 60 | 0 | 20 |
| CM-6 | 680 | 0 | 60 | 520 | 0 | 20 |

| | Root-lesion | | Root-lesion |
|---|---|---|---|
| | 8-Jun-22 | | 28-Oct-22 |
| JordieVs | 60 | | |
| OLgaNewRasp | 0 | | 100 |
| OlgaStrawb | 300 | | |
| Rasp Field | 0 | | |
| Olga | | | |
| Rasp 1 | | | 620 |
| Wrong way | | | |
| Olga-fum | | | 60 |
| Rasp1-fum | | | 0 |
| Wrong Way- fum | | | 0 |

## Appendix Table 4: Verticillium sp. qPCR Results Summary All Years All Berry Sites

Organism(s): Verticillium dahliae, Verticillium albo-atrum

| Client ID | *V. dahliae* DNA ng/g soil | *V. dahliae* cells per gram soil* | *V. albo-atrum* DNA ng/g soil | *V. albo-atrum* cells per gram soil* | *V. dahliae* DNA ng/g soil | *V. dahliae* cells per gram soil* | *V. albo-atrum* DNA ng/g soil | *V. albo-atrum* cells per gram soil* |
|---|---|---|---|---|---|---|---|---|
| Sample Date: | | 5-Jun-20 | | | 28-Oct-20 | | | |
| CM1 | 0.035 | 958 | 0 | 0 | *0* | *0* | *0* | *0* |
| CM2 | 0.01 | 261 | 0 | 0 | *0* | *0* | *0* | *0* |
| CM-3 | | | | | *0.093* | *2555* | *0* | *0* |
| CM-4 | | | | | | | | |
| CM-5 | | | | | | | | |
| CM-6 | | | | | | | | |

| 2021 Crop | *V. dahliae* DNA ng/g soil | *V. dahliae* cells per gram soil* | *V. albo-atrum* DNA ng/g soil | *V. albo-atrum* cells per gram soil* | *V. dahliae* DNA ng/g soil | *V. dahliae* cells per gram soil* | *V. albo-atrum* DNA ng/g soil | *V. albo-atrum* cells per gram soil* |
|---|---|---|---|---|---|---|---|---|
| | | 18-May-21 | | | 5-Oct-21 | | | |
| Oats/clover | **0.000** | **0** | **0.000** | **0** | **0.011** | **291** | **0.000** | **0** |
| Oats/clover | **0.000** | **0** | **0.000** | **0** | **0.020** | **548** | **0.000** | **0** |
| Strawberry | **0.000** | **0** | **0.000** | **0** | **0.071** | **1935** | **0.000** | **0** |
| CFPM | **0.000** | **0** | **0.000** | **0** | **0.017** | **455** | **0.000** | **0** |
| Mustard/oats | **0.000** | **0** | **0.000** | **0** | **0.000** | **0** | **0.000** | **0** |
| Mustard/oats | **0.000** | **0** | **0.000** | **0** | **0.129** | **3547** | **0.000** | **0** |
| | | | | | Oct 26,2021 -PreFumigant | | | |
| | | | | **By Spray Tanks** | **0.000** | **0** | **0.000** | **0** |
| | | | | **Beside Hill** | **0.000** | **0** | **0.000** | **0** |
| | | | | **Raspberry** | **0.000** | **0** | **0.000** | **0** |
| | | | | | Nov 15,2021-PostFumigant | | | |
| | | | | **Beside Hill F** | **0.000** | **0** | **0.000** | **0** |
| | | | | **Sprayer F** | **0.000** | **0** | **0.000** | **0** |
| | | | | **Raspberr F** | **0.000** | **0** | **0.000** | **0** |

| 2022 Field | 2022 Crop | V. dahliae cells per gram soil | V. dahliae cells per gram soil |
|---|---|---|---|
| | | 17-Jun-22 | 28-Oct-22 |
| CM1 | | 0 | 0 |
| CM2 | | 0 | 0 |
| CM-3 | | 1881 | 2713 |
| CM-4 | | 6760 | 559 |
| CM-5 | | 0 | 0 |
| CM-6 | | 388 | 592 |
| | | | |
| JordieVs | | 0 | |
| OLgaNewRasp | | 0 | |
| OlgaStrawb | | 0 | |
| Rasp Field | | 0 | |
| Olga | | 0 | 0 |
| Rasp 1 | | | 0 |
| Wrong way | | | 0 |
| Olgafum | | | 0 |
| Rasp1 fum | | | 0 |
| Wrong Way fum | | | 0 |

*cells per gram soil estimate based on known DNA size of V. dahliae genome = 36.5 fg/cell

**Appendix Figures 1; CLIMATE FIELDVIEW Image Summary**

Geo-referenced Sample Locations

May 14, 2021


2021
Field Health
540
Area (%)
High Biomass
32.4%
9.7%
27.6%
30.3%
0%
Low Biomass
540
True Color
Recenter
Region
Google
Map data ©2022 Imagery ©2022 , CNES / Airbus, Maxar Technologies, USDA Farm Service Agency
Terms of Use
Report a map error

July 13, 2021


2021
Field Health
540
High Biomass
Area (%)
29.1%
10.8%
29.6%
30.6%
0%
Low Biomass
540
True Color
Recenter
Region
Google
Map data ©2022 Imagery ©2022 , CNES / Airbus, Maxar Technologies, USDA Farm Service Agency
Terms of Use
Report a map error

July 23, 2021

2021
Field Health
540
Area (%)
High Biomass
0%
33.7%
33.9%
32.4%
0%
Low Biomass
540
True Color
Recenter
Region
Google
Map data ©2022 Imagery ©2022 , CNES / Airbus, Maxar Technologies, USDA Farm Service Agency
Terms of Use
Report a map error

Aug 14, 2021


2021
Field Health
540
High Biomass
Area (%)
0%
39.2%
31.6%
14.9%
14.2%
Low Biomass
540
True Color
Recenter
Region
Google
Map data ©2022 Imagery ©2022 , CNES / Airbus, Maxar Technologies, USDA Farm Service Agency
Terms of Use
Report a map error

Sept. 8, 2021


2021
Field Health
Area (%)
High Biomass
9.7%
30.5%
26.8%
33%
0%
Low Biomass
540
540
True Color
Recenter
Region
Google
Map data ©2022 Imagery ©2022 , CNES / Airbus, Maxar Technologies, USDA Farm Service Agency
Terms of Use
Report a map error

Sept.21, 2021


2021
Field Health
540
Area (%)
High Biomass
0%
24.6%
36%
7.3%
32.1%
Low Biomass
540
True Color
Recenter
Region
Google
Map data ©2022 Imagery ©2022 , CNES / Airbus, Maxar Technologies, USDA Farm Service Agency
Terms of Use
Report a map error

Oct.11, 2021


2021
Field Health
540
Area (%)
High Biomass
0%
31.1%
33%
35.9%
0%
Low Biomass
540
True Color
Recenter
Region
Google
Map data ©2022 Imagery ©2022 , CNES / Airbus, Maxar Technologies, USDA Farm Service Agency
Terms of Use
Report a map error