USING COVER CROPS AND SOIL AERATION TO MITIGATE IMPACT OF PHYTOPHTHORA IN MACADAMIA ORCHARDS

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Macadamia (*Macadamia integrifolia*) production in Hawai'i has declined in recent years due to several factors. Average annual gross yield for macadamias in Hawai'i was 58.6 million lbs with an average of 3,080 lbs per acre from 2000-2010 (USDA NASS 2011). For the 2022-2023 harvest season, production declined to 36.8 million lbs with an average yield of 2,300 lbs per acre, and farmgate value of only $30.9 million (USDA NASS 2024). Feral hog damage, Macadamia Felted Coccid (MFC), and marketing challenges were all cited by farmers as issues affecting production (USDA NASS 2024). However, root diseases caused by *Phytophthora* spp. have long been reported to cause slow and quick decline diseases of macadamia (Ko and Kunimoto, 1994) that contribute to the decline in health and production of macadamia trees.

Fig. 1. Quick decline of macadamia caused by Phytophthora spp. where tree branches die back. Infected trunks form girdling, trunk bleeding, and tree shows signs of decline.

Phytophthora spp.

Phytophthora is an oomycete, or water mold, which is a fungus-like organism known for causing damage across a wide range of crops throughout the world (Laurens et al. 2012). As of 2012, there were approximately 100 species of *Phytophthora* described in scientific literature (Laurens et al. 2012). In Hawai'i, a range of *Phytophthora* spp. affect many economically and culturally important species such as macadamias, orchids, papaya, tomato, avocado, ʻōhi'a and many other plants through symptoms such as root rot, blight, and fruit rot (Mueller-Dombois, 2022). In macadamia orchards, the main species of *Phytophthora* causing damage in Hawai'i are suspected to be *Phytophthora tropicalis, Phytophthora*

cinnamomi, and *Phytophthora heveae* (Sugiyama et al., 2020). Infected macadamia trees typically show symptoms of leaf yellowing or browning, stem cankers, trunk bleeding, sparse or bare canopy (Fig. 1), and general tree decline resulting from the pathogen attacking the root and tree vascular system (Keith et al., 2010; Sugiyama et al., 2020, Zentmyer and Storey., n.d.). These symptoms typically show up after prolonged periods of wet weather that allow *Phytophthora* to proliferate and spread (Akinsanmi et al., 2013). *Phytophthora* damage in macadamias is thought to be worsened by poor soil drainage and fertility, tree age, and susceptibility of the root stock and tree variety (Akinsanmi et al., 2013).

While no formal damage assessments have been completed, macadamia industry stakeholders recognize that tree death and decline caused by disease is a major culprit of yield loss. It has been observed that growers located in heavy rainfall areas where soils are prone to prolonged periods of waterlogging are experiencing accelerated tree death and decline. Informal assessments of *Phytophthora* damage, through conversations and visits with Hawai'i Macadamia Nut Association farmers, indicate that an average of 10-20% of trees are in decline or lost.

This project evaluated the potential of using cover crops and soil aeration as cultural control methods in macadamia orchards to mitigate the impact of *Phytophthora* spp. A cover crop mix of cowpeas (*Vigna unguiculata*), sunn hemp (*Crotalaria juncea*), black oats (*Avena strigosa*), sudangrass (*Sorghum drummondii*), brown mustard (*Brassica juncea*), tillage radish (*Raphanus sativus*), and buckwheat (*Fagopyrum esculentum*) were planted in between tree rows to potentially improve soil physical, biological, and chemical properties aiming to suppress *Phytophthora* spp.

Fig. 2. Cover crop mix planted in between macadamia nut trees.

At the site of this project in Kohala, Hawai'i, the organic macadamia farm managed by Island Harvest has sustained significant tree damage that is thought to largely be caused by *Phytophthora* spp. In certain blocks, Island Harvest has seen tree mortality rates near 50%, most likely due to *Phytophthora* spp. (Fig. 3). This has resulted in yield loss and makes clearing and replanting the orchard an impending necessity in some areas. However, most of Island Harvest's orchards show early signs of decline and severe yield loss has yet to be realized. For Island Harvest and many macadamia farmers in Hawai'i, it is imperative to mitigate the damage caused by *Phytophthora* spp.

Fig.3: Aerial view of moderate tree decline (left) and more severe tree decline (right) believed to be caused by Phytophthora at Island Harvest in Kohala, Hawai'i.

Cover Crops and Soil Aeration

Research on the use of cover crops to improve soil health and suppress plant-parasitic nematodes in Hawai'i has been documented (Marquez et al., 2022; Wang et al., 2008; Paudel et al., 2022), but limited research was conducted for macadamia production. Using cover crops in established orchards and prior to replanting of new orchards could have the potential to improve soil health and mitigate the impact of *Phytophthora* spp. through the improvement of physical, chemical, and biological characteristics of the soil.

This project investigated the use of aeration and mixed cover crops in macadamia orchards in an attempt to enhance the soil's ability to antagonize *Phytophthora* spp. Aeration and cover crop planting can be done at scale through the use of machinery, such as the AerWay AWATS 100 AG4 (Salford Group Inc., Osceola, Iowa), which Island Harvest found to be an effective tool. The aerator has shatter tines for soil aeration to loosen compacted soil, followed by seeder boxes at the back to direct seed through drop tubes, and a bottom deflector plate to bury seeds to the desired soil depth (Fig 4). This machine accomplishes generally uniform seed distribution and provides good seed to soil contact without aggressive soil disturbance.

Fig. 4. AerWay AWATS 100 AG4 manufactured by Salford Group Inc. Osceola, Iowa.

It was hypothesized that the use of cover crops and aeration could improve soil health characteristics and mitigate a conducive environment to *Phytophthora* spp., thereby improving macadamia tree health. However, due to the need of a

clean orchard floor to harvest macadamia nuts, the cover crop was terminated and removed annually during the harvest season (August to December). Using an aerator to reseed the cover crop each year reduced the disturbance to the soil. Fig. 5 illustrates the hypothesized changes in soil characteristics between the control and cover crop treatments. The cover crop mix was intended to positively alter the soil rhizosphere of the macadamia orchards through root exudates, ground cover, and organic addition that stimulate soil microbial activities.

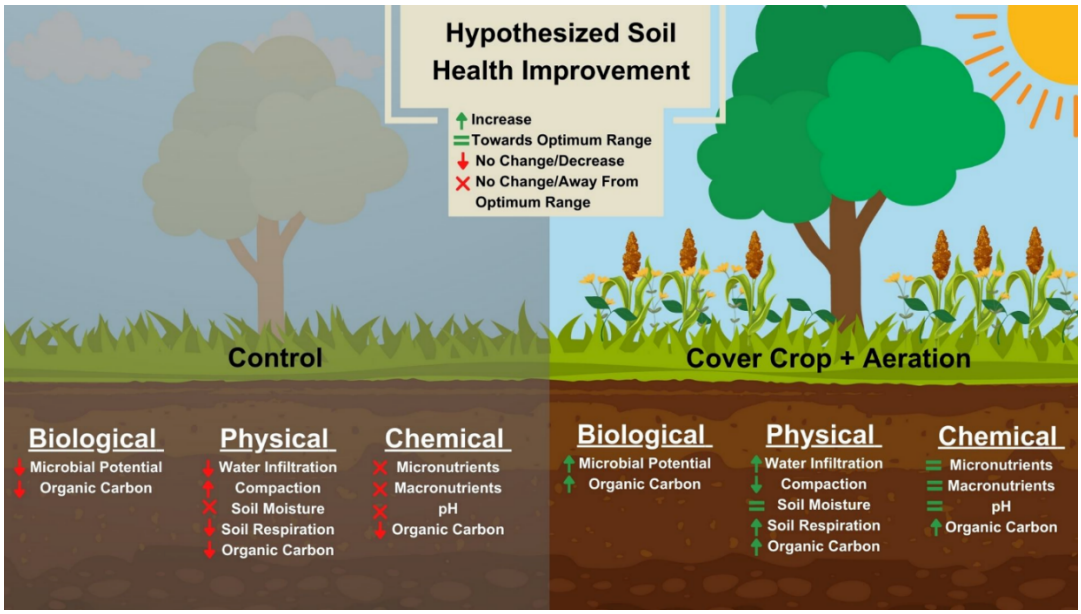

Fig. 5. Hypothesized changes in soil health metrics of the control (left) and cover crop treatments (right).

Field Study

A 2-year field trial was conducted in a mature certified organic macadamia orchard in Kohala, Hawai'i, managed by Island Harvest. The soil is the Kohala soil series classified as an Inceptisol with silty clay texture. The orchard floor vegetation is exclusively managed by mowing. The macadamia cultivars in the field are a combination of varieties developed by the Hawai'i Agricultural Experiment Station (HAES): HAES 246 (Keauhou), HAES 344 (Ka'ū) and HAES 508 (Kākea). These varieties are scion grafted onto primarily HAES 660 (Kea'au) rootstock. Average annual rainfall was approximately 55 inches, with monthly rainfall ranging from 2.8 to 7.8 inches (Giambelluca et al., 2013). The orchard site was considered to have moderate levels of tree decline.

The three treatments tested in the macadamia rows were 1) cover crop and aeration, 2) aeration only, and 3) untreated control with existing grasses and weeds, with occasional bare ground in heavily shaded areas. Treatments were arranged in a randomized complete block design with 4 replicated blocks, each block were 60 ft x 150 ft (9,000 ft^2) in size with approximately 20 trees of >30-years old spaced 15 ft x 30 ft apart (Fig. 6).

Fig. 6. Project layout showing four blocks of three treatments.

The cover crop mix composed of sunn

Fig. 7. Pictures showing seeder and cover crop and aeration treatments.

hemp, cowpea, tillage radish, black oat, brown mustard, sorghum-sudangrass and buckwheat was planted during the off harvest season from January to June of 2022 and 2023. Each cover crop was a 90-day cycle, thus two consecutive cycles were planted between January and June. In each cycle, the cover crop was terminated with a flail mower. The composition of the mix was selected for various benefits: building soil organic matter (black oat and sorghum-sudangrass), adding soil nitrogen (cowpea and sunn hemp), breaking up soil compaction (tillage radish), attracting beneficial insects (buckwheat), and potential biofumigation (brown mustard). An AerWay aerator with over seeder attachment was used to seed the cover crops (Fig. 7A). The seeder attachment was shut off for the aeration only treatment. Aeration tines penetrate the soil 6-8 inches deep (Fig. 7B).

Most legumes, such as sunn hemp and cowpea, attract Southern Green stink bug (*Nezara viridula*), a common pest of macadamia nuts (Evans et al., 1988). The cover crop and surrounding area were informally monitored for potential increases in stink bug populations during the project and few were found. Island Harvest did see an overall increase in stink bug damage to macadamia nuts during the 2023 harvest season, but this was found throughout the orchards and was not exclusive to the project area. Further research would need to be conducted to evaluate the impact of cover crops in macadamias orchards as it pertains to attracting both pests and beneficial insects.

Results

Unfortunately, two years after examining the interrow soil treatment, cover crop plus aeration and aeration treatments did not improve macadamia tree health (Fig. 8A). According to the tree health scale used, a lower score is a healthier tree (0 = healthy tree) and a higher score indicates a less healthy tree (5 = dead tree). No difference was observed across years in the tree health rating.

The soil health score from Haney Test showed a significant increase in Year 2 compared to Year 1 and baseline data, but there was no difference among the treatments (Figure 8B). This large increase in soil health score in year two, across treatments and the control, is thought to be due to sampling error and not due to actual changes in soil health.

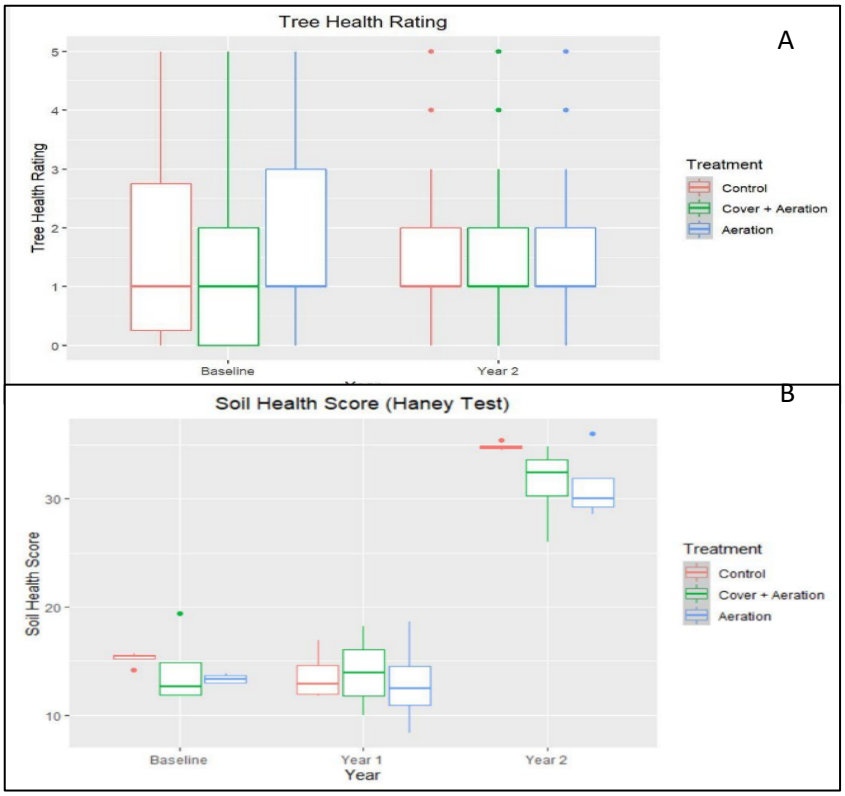

Fig. 8. A) Tree health rating and B) Soil health score across treatments.

On the other hand, water infiltration rate improved in year two for both aeration and cover crop with aeration treatments. Infiltration was measured in the time it took for a fixed amount of water to infiltrate the soil, i.e. lower means better infiltration. Additionally, the data from year two showed that aeration alone, and cover cropping with

aeration improved water infiltration rates compared to the control. When a post hoc mean comparison test (ANOVA) was performed, the aeration, and cover crop and aeration treatments were significantly different from the control, providing some evidence of soil property improvement by the two treatments (Fig. 9).

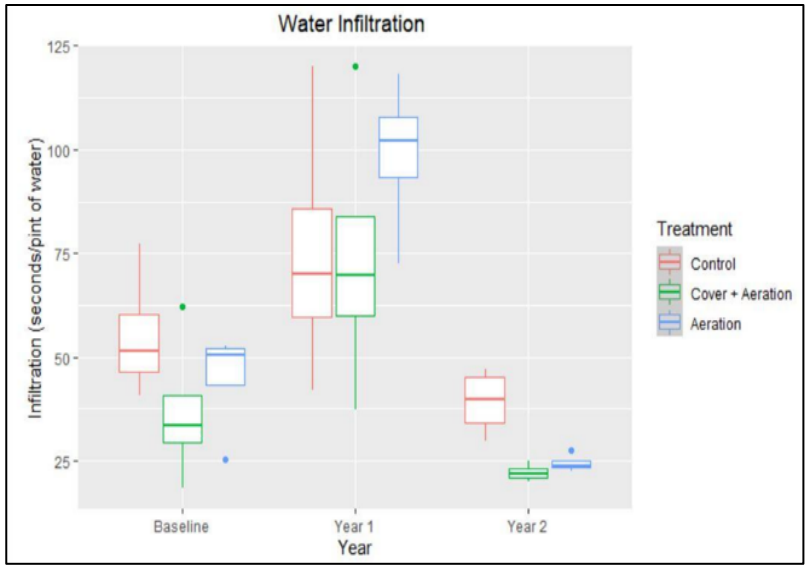

Fig. 9.
Water infiltration time across treatments and years.

Conclusion

Given the decline of the Hawai'i macadamia industry and the limited adoption of chemical control by growers against *Phytophthora* spp., it is important that alternatives to mitigating pathogen impact be explored. *Phytophthora* causes severe plant disease all over the world to macadamia and many other crops and some growers, particularly certified organic producers, do not have the options or desire to use chemical controls. Providing cultural control methods for pathogen suppression, that have other potential soil and plant health benefits, can give farmers a more holistic approach to managing the health and productivity of their crops.

Although this project was unable to show that aeration or cover crops with aeration can suppress *Phytophthora*, nor improve soil health, there were increases in soil health metrics, such as soil organic matter, available nitrogen, and the Haney Test soil health score over the years. The increases between the two years could be due to sampling error from variance in soil sampling depth and location.

Lack of cover crop and aeration effects in this trial could be due to some difficulties in establishing the cover crop under the canopy of macadamia trees. In addition, existing ground cover (grasses and weeds) also provides similar benefit as a cover crop. It would be helpful to conduct a similar study in a non-organic orchard where control plots were bare ground instead of with existing vegetative cover.

It is unlikely that the use of short-term cover crops and aeration alone in between tree rows can suppress *Phytophthora* damage in mature macadamia orchards. Future research should explore cover crops with toxicity as a soil biofumigant against *Phytophthora* and those that grow well in Hawai'i orchard systems. Alternatively, cover crops could be installed in newly transplanted macadamia orchard before intense harvesting takes place.

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