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Solarization and Cover Cropping as Alternatives to Soil Fumigants for Nematode Management in Hawai'i's Pineapple Fields

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Reniform nematode damage on pineapple

Under ideal conditions, one pineapple cropping cycle is composed of three harvests (plant crop plus two ratoons) in a 3–4 year span. When reniform nematodes (*Rotylenchulus reniformis*, Fig. 1) are present, however, marketable yields can be reduced up to 38 percent in the plant crop harvest and 60 percent in the first ratoon (Fig. 2).

The nematicides era

Nematicides are the most-used pesticides in pineapple production in Hawai'i and contribute significantly to the production cost. Since the 1940s, pineapple producers in Hawai'i have relied primarily on either fumigant or non-fumigant nematicides, including methyl bromide, ethylene dibromide (EDB), 1,2-dibromo-3-chloropropane (DBCP), ethoprop, and fenamiphos, but the era of reliance on these products has nearly come to an end in the US and other countries. Unfortunately, many of the more environmentally friendly products that have recently come on the market are ineffective in controlling nematode damage to pineapple (Sipes 2006). Currently, pre-plant fumigation with 1,3-dichloropropene (1,3-d, Telone®) is applied to approximately two-thirds of the pineapple fields in Hawai'i for managing reniform and root-knot nematodes (Sipes 2000). To limit the risk of losing this nematode management option, alternative methods should be researched.

Figure 1. Stages of reniform nematodes (from left): vermiform stage, swollen female, and mature kidney-shaped female.

Needs of small-scale pineapple growers

Hawai'i's pineapple production has been shrinking since the 1950s. The number of farms growing pineapples in the state fell from 47 (61,000 acres) in 1970 to 15 in 2002 (19,100 acres) (USDA Economic Research Service 2003). Most recently, two of the largest pineapple producers have ceased operations in Hawai'i, in part due to rising production costs, competition from countries with low production costs, and tight U.S. labor demands (USDA Economic Research Service 2003). These closings, however, have opened a niche market in Hawai'i for small-scale production of fresh pineapple. These smaller-scale farms are usually unable to afford nematicide fumigation, or lack the necessary equipment for its application. Thus there is an urgent need for non-chemical alternatives to

Figure 2. Damage to pineapple plants caused by reniform nematodes (foreground) compared to nematicide-treated plots in the background. Plants severely infected by nematodes show water and nutrient stress, with stunted growth.

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nematode management for pineapple. Cover cropping and soil solarization are two approaches under investigation.

Cover crops

Cover crops are either grown between cash-crop cycles or intercropped with the cash crop to provide ground cover, replenish soil nutrients, and reduce disease pressure. If selected carefully, they can also suppress weeds and plant-parasitic nematodes. Several cover crops have been evaluated in Hawai'i for managing nematodes before planting pineapple (Fig. 3).

All of these cover crops developed well in Hawai'i's tropical climate. However, African marigold was a good host of reniform nematodes. Rapeseed suppressed the population of reniform nematodes but was a good host of root-knot nematodes (*Meloidogyne javanica*). Sunn hemp is a poor host of reniform and root-knot nematodes, and when incorporated into the soil produces monocrotaline, a compound that inhibits nematode movement and delays nematode development. Thus sunn hemp appears promising for managing nematodes in pineapple production systems. To further improve nematode management in pineapple soils, we are examining the effect of integrating sunn hemp cover cropping with soil solarization.

Fig. 3. Three cover crops were tested before pineapple planting at the Whitmore Experiment Station: 'Cracker Jack' African marigold (*Tagetes erecta*), 'Dwarf Essex' rapeseed (*Brassica napus*), and 'Tropic Sun' sunn hemp (*Crotalaria juncea*). A weedy fallow treatment was the control.

Figure 4. Soil solarization is killing some weeds under the solarization mulch.

Soil solarization

Soil solarization (Fig. 4) is done by heating the soil beneath clear plastic mulch for 6 weeks so that it reaches temperatures detrimental to soilborne pests (Katan et al. 1976). This method has been used successfully against plant-parasitic nematodes and soil-borne pathogens in several crops and regions around the world, especially in hot climates (Katan 1981, 1976; Stapleton and Devay 1983). Pineapple growers in Hawai'i can take advantage of the climate during extended periods of hot weather to do soil solarization efficiently. It is important to note that for high efficiency, the plastic mulch needs to be transparent polyethylene (1 mil thick) with ultraviolet inhibitors. This material is not commonly available from agricultural or horticultural suppliers in Hawai'i and must be ordered from the companies that manufacture it.

Approximately 14 hours at ≥ 42°C was sufficient to kill all root-knot nematodes in sand tubes, but at sublethal temperatures (40–42°C) at least 46 hours were required to kill them all (Wang and McSorley 2008). Heald and Robinson (1987) also determined that 42°C was lethal to reniform nematodes. A solarization treatment done during the summer (May–July) at the Whitmore Experiment Station on O'ahu maintained temperatures above 42°C in the top 5 cm of soil for 174 hours. Unfortunately, the deeper soil layer (>15 cm) could not reach temperatures high enough to kill plant-parasitic nematodes.

Reniform nematode management challenges

Conventional practice in pineapple systems includes leaving pineapple fields fallow for 6–12 months after the previous crop is plowed under. However, reniform nematodes respond to the lack of a host plant by entering into a dormant state known as anhydrobiosis (Fig. 5). With this survival strategy, the nematode coils and can survive months to years without feeding (Tsai 1978). It is well accepted that killing the vermiform stages of reniform nematodes might be easier than killing them in their anhydrobiotic state. Therefore, we are testing a more efficient approach to nematode management by integrating soil solarization with a cover crop that is a poor host of the reniform nematode.

Integrating cover crops and solarization

Sunn hemp (*Crotalaria juncea*) is a tropical leguminous plant that is recommended as green manure crop and a cover crop for soil conservation (Hooks et al. 2006). In addition, it is a poor host of reniform nematodes; they can penetrate the roots, but their maturation is drastically delayed (Wang et al. 2001). Thus, sunn hemp "traps" reniform nematodes and prevents them from entering the state of anhydrobiosis. Also, because sunn hemp foliage contains compounds that are toxic to reniform nematodes, when it is incorporated into the soil as green manure, these compounds are released to act as nematicides and suppress the nematodes. By integrating sunn hemp cover cropping with soil solarization, it could serve as a soil biofumigant against reniform nematodes and other soil pests.

A field trial conducted at Whitmore Experiment Station in 2008–2009 compared planting sunn hemp (SH) for 5 months, solarization for 2 months (Sol), and sunn hemp for 3 months followed by solarization for 2 months (SH+Sol) to a weedy fallow control. Pineapple slips were planted into these four treatments. At 3 months after pineapple planting, the number of reniform nematodes recovered was significantly lower in the SH treatment than the control. Integration of sunn hemp and solarization significantly suppressed weeds after pineapple planting without application of herbicides.

Other benefits of integrating a sunn hemp cover crop with soil solarization

Along with the promising results of weed and nematode suppression with sunn hemp, an additional benefit is improving soil conditions. In addition to its properties as a green manure, adding organic matter and nitrogen to the soil, sunn hemp reduces soil erosion during fallow periods and increases the population of many beneficial nematodes and soil microarthropods that play important roles in soil nutrient cycling. Researchers at CTAHR are currently monitoring the effects of growing cover crops on beneficial soil organisms as well as the effects of soil solarization in pineapple fields. Previous research verified that sunn hemp consistently increases the number of beneficial free-living nematodes in the soil (Wang et al. 2001, 2002, 2003) but that soil solarization temporarily suppresses these beneficial organisms (Wang et al. 2006). However, integrating soil solarization with a leguminous cover crop could reduce the negative impact of soil solarization on beneficial soil organisms while improving the pest-suppression effect achieved by cover cropping alone (Wang et al. 2006). Analysis of a 3-month-old pineapple planting previously fumigated with Telone revealed a significant reduction in the total number and diversity of free-living (non-plant-parasitic) nematodes compared to a neighboring field previously fallowed or planted with sunn hemp (Wang, unpublished).

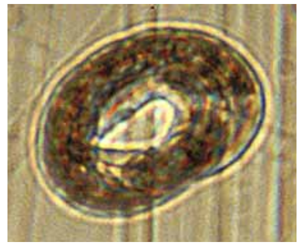

Figure 5. The reniform nematode enters a dormant state (anhydrobiosis) by coiling its body.

Cost evaluation

Sunn hemp seeds cost $3/lb, and the recommended seeding rate in Hawaii is 30–40 lb/acre. Approximately 18,000 gal of water is required to irrigate the sunn hemp cover crop for 3 months during the summer. However, the sunn hemp cover crop can be rain-fed during the winter in Hawai'i. Solarization mulch costs $329/acre. In contrast, Telone II (1,3-D) fumigation costs $525/acre when applied at 30 gal/acre. Thus the cost of sunn hemp plus solarization is cheaper than the 1,3-D treatment.

Limitations

One major limitation to growing sunn hemp in some pineapple fields is low soil pH (3.9–5.0). Pineapple grows well at low soil pH, and some farms maintain low soil pH to avoid *Phytophthora* rot. Sunn hemp does not grow well at soil pH less than 6.0, so under these conditions it should not be planted as a cover crop. However, some pineapple farmers in Hawai'i adjust the soil pH every 5 years, making conditions for planting sunn hemp acceptable. Sunn hemp is also suitable as a cover crop in organic pineapple fields where compost is added before planting the crop. The growth of sunn hemp at different pH levels can be seen in Figure 6. Perhaps more pineapple acreages should be considered for pH adjustment if *Phytophthora* rot is not a threat.

More soil solarization research is needed to find ways to raise the temperature of the soil in deeper layers. Soil fumigants are generally injected 12 inches below the soil surface to kill nematodes deeper in the soil. Preliminary data indicate that incorporating sunn hemp residues can add heat to these deeper soil layers through its decomposition, but the data are not consistent.

Conclusion

Integrating sunn hemp with soil solarization is promising for suppressing reniform nematodes and weeds in

Soil pH 3.9, not limed; sunn hemp planted in April.

Soil pH 4.5, limed just before sunn hemp planting in November.

Soil pH 6.0, routinely limed every 5 years; sunn hemp planted in May.

Figure 6. Variation in sunn hemp establishment approximately 2 months after planting in three fields with different soil pH and planting seasons.

pineapple production. Although reniform nematodes reestablished faster in fields receiving these alternative treatments than in Telone-treated fields, populations of beneficial organisms involved in soil nutrient cycling were enhanced by them but reduced by Telone. The cost of using sunn hemp plus soil solarization is slightly lower than using Telone, and these practices can readily be adopted by smaller-scale growers. Most pineapple production in Hawai'i has done away with ratoon cropping and shifted to repeated plant-crop harvest for the fresh-fruit market. Thus despite its less-efficient nematode suppression compared to Telone, sunn hemp plus solarization is more compatible with this shorter production cycle.

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