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Protecting Crops from Nematode Pests: Using Marigold as an Alternative to Chemical Nematicides

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The primary soil-borne plant-parasitic nematodes impacting cropping systems in Hawai'i are the root-knot, reniform, cyst, burrowing, and lesion nematodes, all of which contain spear-like mouthparts used to puncture plant roots and obtain nutrients. These nematodes cause significant economic damage to a wide variety of crops. After crops are infected with nematodes, crop yield and quality are reduced, either directly from root deformation caused by nematode feeding or indirectly from predisposition to infection by other pathogens that results from nematode penetration into the roots. The methods most frequently used for managing nematodes in agriculture include rotating crops with plants that are not hosts of plant-parasitic nematodes, using resistant plants if available, and applying chemical nematicides. Additional methods include soil solarization and the use of organic amendments, trap crops, microbial biocontrol agents, and plants that are antagonistic to parasitic nematodes. This publication focuses on the latter alternative and specifically discusses the potential use of marigold plants for managing plant-parasitic nematodes found in Hawai'i and other regions.

Mechanism by which marigold suppresses nematode pests

While marigolds (*Tagetes* species) are typically grown for ornamental purposes as bedding plants, studies have found that they can be highly toxic to plant-parasitic nematodes and are capable of suppressing a wide range (up to 14 genera) of nematode pests. The nematicidal potential varies with the marigold species and cultivar, the nematode species targeted, and soil temperature. The marigold species most often used for nematode control are *Tagetes patula*, *T. erecta*, and *T. minuta*. The key mode by which marigolds suppress plant-parasitic nematodes is through a biochemical interaction known as allelopathy. Allelopathy is a phenomenon where a plant releases compounds that are toxic to other plants, micro-organisms, or other organisms, such as nematodes.

Marigold plants produce a number of potentially bioactive compounds, among which α-therthienyl is recognized as one of the most toxic. This sulfur-containing compound is abundant in marigold tissues, including roots. It has nematicidal, insecticidal, fungicidal, antiviral, and cytotoxic activities, and it is believed to be the main compound responsible for the nematicidal activity of marigold. Thus nematodes may be killed either by entering the root system of a marigold plant or contacting soil containing marigold's bioactive compounds.

The nematicidal activity of marigold has been detected in roots of growing plants but not in root or leaf extracts. Some studies have shown that these nematicidal properties result from a sequence of events in the marigold roots triggered by penetration and movement of nematodes through the root tissue, and the end product of these reactions is thought to kill nematodes. Nematicidal compounds apparently permeate from marigolds' root tissues into nematodes attached to the root, but they are also believed to kill nematodes found in the rhizosphere, the soil near marigold roots. Thus, marigold is believed to be most effective in suppressing plant-parasitic nematodes when actively growing, but it is not as effective when

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Figure 1. A patch of marigold, *Tagetes patula* 'Single Gold' at the early flowering stage. Behind it is a border row of a sorghum sudangrass hybrid. *Photo: C.R.R. Hooks*

incorporated as crop residues or root extracts. Several other plants with nematicidal properties, including sunn hemp (*Crotalaria juncea*), are believed to release nematicidal compounds when incorporated into the soil and thus do not require root penetration to effectively kill nematodes.

Some researchers believe that marigold root exudates prevent the nematodes from developing and their eggs from hatching. However, the nematode species and growth stages suppressed by marigold vary with the marigold species. For example, *Tagetes patula* 'Single Gold' (synonym: 'Groundcover') (Figure 1) is an extremely poor host of the root-knot nematode, and there is limited penetration and development by this nematode on this plant. However, another marigold species, *T. erecta* 'Cracker Jack' (Figure 2), behaved as a trap crop: root-knot nematodes were attracted to and entered its roots, but the development of their offspring was impeded. In other cases, marigolds may behave as a trap crop by allowing penetration of nematodes but inhibiting their subsequent development and reproduction.

Knowing the marigold and identifying the targeted nematode species

It is critically important to know which nematode species is responsible for crop damage before selecting a marigold plant. The bioactive compounds of different marigold species and cultivars may differ in composition, quality, and quantity. Thus, certain species may be highly effective against one nematode species but have limited to no impact on or possibly increase populations of other plant-parasitic nematodes. Table 1 summarizes the genera of nematodes commonly found in Hawai'i and the marigold cultivars that are resistant to these nematodes. *Tagetes patula* 'Single Gold', *T.* hybrid 'Polynema', and *T. erecta* 'Cracker Jack' effectively suppressed four root-knot nematode species: *Meloidogyne arenaria*, *M. incognita*, *M. javanica*, and *M. hapla*. Research-

Figure 2. Flowering marigold *Tagetes erecta* 'Cracker Jack' interplanted with cauliflower. *Photo: C.R.R. Hooks*

ers in Hawai'i reported that marigolds 'Polynema' and 'Cracker Jack' are good hosts for reniform nematodes but that marigold *T. patula* 'Boy-O-Boy' suppresses reniform nematode populations. Root-knot and reniform nematodes are commonly found infesting agricultural fields in Hawai'i; therefore, marigold 'Single Gold' is recommended for use in fields containing populations of both these nematodes. Field experiments conducted in California showed that growing marigold 'Single Gold' consistently suppressed root-knot nematode and, consequently, lowered root galling of tomato grown over several subsequent seasons and increased tomato yield by about 50 percent. In Hawai'i, researchers found that *T. patula* was the most effective cover crop for improving taro (*Colocastia esculenta*) yields among 22 cover crops tested in fields infested with *M. javanica*.

The marigold *T. patula* also suppresses lesion nematodes, *Pratylenchus penetrans* and *P. pratensis*, which are parasites of ornamentals, coffee, and other important crops. *Tagetes erecta* lowered levels of burrowing (*Radopholus similis*), spiral (*Helicotylenchus multicinctus*), and lance (*Hoplolaimus indicus*) nematodes when intercropped with a highly susceptible banana crop. *Tagetes erecta* produces more biomass than several cultivars of *T. patula* and thus establishes well in the field, making it ideal for use as a cover crop. However, *T. patula* 'Single Gold' can also generate a significant amount of biomass, similar to *T. erecta* 'Cracker Jack', and thus may be an ideal marigold cover crop.

How to use marigold for nematode suppression

It is important to know that α-terthienyl compounds in marigold have limited nematicidal activity when incorporated into the soil. Only living marigold root systems exhibit significant nematicidal properties. For example, even though a *Tagetes patula* 'Single Gold' crop consistently suppressed a diverse range of plant-parasitic

Table 1. Susceptibility of several marigold cultivars to some commonly occurring plant-parasitic nematodes in Hawai'i at temperatures less than 30°C.

Marigold	Root-knot[z]	Reniform[y]	Burrowing[x]	Lesion[w]
Tagetes patula	-	-	-	R
Tagetes patula 'Single Gold'	R[v]	-[v]	-	-
Tagetes patula 'Boy-O-Boy'	-	R	-	-
Tagetes hybrid 'Polynema'	R	S	-	-
Tagetes erecta	-	-	R[u]	-
Tagetes erecta 'Cracker Jack'	R	S	-	R
Tagetes signata	R	-	-	-

z *Meloidogyne incognita, M. javanica, M. arenaria,* and *M. hapla*.
y *Rotylenchulus reniformis*
x *Radopholus similis*
w *Pratylenchus penetrans* and *P. pratensis*
v R = resistant, S = susceptible, - = undetermined.
u Resistant but fail to suppress the nematodes when planted between burrowing nematode infected and non-infected plants.

nematodes, when residues were incorporated into the soil it did not suppress the root-knot nematode as well. The critical stage for marigold suppressive effect is during its growth. Therefore, to maximize the nematicidal activities of marigold, it should not be tilled in until fully established (3–4 months). As such, marigolds are typically grown as a cover crop or planted in rotation with the cash crop to manage nematodes.

In situations where farmers have a small acreage and cannot afford to have land out of production, rotating marigolds with their cash crops might not be practical or economically feasible, especially if there is no direct economic return from planting marigold. An alternative approach is to use marigold as an intercrop. This approach may not be as potent as applying a nematicide directly into the root zone of a cash crop, but because the nematicidal activity of marigold should permeate to surrounding soils, there will be some nematode suppression in the neighboring cash crop. For example, intercropping banana with marigolds 'Cracker Jack' and 'Single Gold' reduced population densities of *Meloidogyne*, *Radopholus*, *Rotylenchulus*, and *Pratylenchus* nematodes and reduced banana root damage. In another study, intercropping sugarcane with *T. erecta* reduced population densities of spiral nematodes and increased sugarcane yield and quality. Tomato infections by the false root-knot nematode were reduced in a tomato and 'Cracker Jack' intercrop compared to tomato monoculture.

Effects of marigold on non-target organisms

Although marigold plants produce nematicidal compounds, their root extracts were found to have no suppressive effect on several other soil microorganisms. Further, although incorporating marigold residues into the soil does not enhance the nematicidal effect, it may enhance propagules of nematophagous (nematode-trapping) fungi that adhere to or prey on nematodes. Once attached, the fungal hyphae penetrate the nematode, utilize it as a source of food, and thus kill it. When marigold residues were incorporated into the soil of a pineapple field, nematode-antagonistic activity was enhanced, but this was not sufficient to suppress populations of reniform nematodes.

Effect of temperature on marigold nematicidal activity

The level of nematode suppression by marigold is affected by temperature. For example, marigold 'Single Gold', *T. patula* 'Tangerine', and *T. erecta* 'Flor de Muerto' suppressed root-knot nematode infection on subsequent tomato plants compared to a fallow treatment at 20–30°C. However, *T. signata* 'Tangerine Gem' and *T.* hybrid 'Polynema' failed to suppress *M. incognita* at temperatures higher than 30°C. *T. erecta* 'Cracker Jack' only reduced *M. incognita* densities at temperatures ranging from 10 to 30°C. Thus it is critical to take in consideration the agro-climate of an area when selecting a marigold species for nematode suppression.

Limitations on and concerns about using marigold for nematode suppression

Marigolds are sensitive to day-length, having what is called short-day photoperiodism. In general, the plant remains vegetative when days are long and flowers when days are short. Because Hawai‘i's day-length is generally short compared to the summer months of temperate zones, marigolds with a strong sensitivity to short-day photoperiod tend to flower quickly even during our longest days.

Different marigold species have different sensitivity to day-length. *Tagetes patula* has a stronger response and flowers more readily than *T. erecta*. Thus *T. patula* 'Boy-O-Boy' may not serve as a good cover crop in Hawai‘i because it starts to bloom before establishing much biomass, even when planted during the summer. *T. erecta* is less sensitive to photoperiod, remaining vegetative when day-length is above 12.5–13 hours. Therefore, *T. erecta* 'Cracker Jack' can produce considerable biomass during the summer in Hawai‘i, establishing a more extensive root system that can suppress substantially greater numbers of plant-parasitic nematodes.

Marigold can serve as a host for some other pests, such as thrips and spider mites. Spider mites especially can be a problem during hot, dry weather. Some marigold varieties, such as *T. patula* 'Single Orange Scarleteade', are very susceptible to mites. Thrips can be a major problem because they can transmit tomato spotted wilt virus (TMSV), a serious virus disease of a wide range of vegetable crops including tomato and peppers. Other diseases of marigold include damping off (*Pythium* and *Rhizoctonia*), grey mold (*Botrytis*) of flowers, southern bacterial wilt (*Pseudomonus solanacearium*), and bacterial leaf spot (*Pseudomonas syringae* var. *tagetes*). These can be problems when marigold is intercropped with plants susceptible to these pathogens.

Plant-parasitic nematodes generally have a wide host range, and it is therefore important that the marigold crop is free of weeds. Otherwise, nematodes may survive and multiply on the weeds' roots. If weeds are not well controlled, nematode management by marigold may be ineffective. The disadvantage of using marigold as an intercrop is that chemical herbicides are typically compatible with nematicide application but may not be used in a cash crop intercropped with marigold because the herbicide sprays may stunt or kill the marigold. The difficulties associated with weed control may limit its adoption by growers. Further, if sown as an intercrop in a low growing vegetable production system, and not properly managed, marigolds themselves may act as weeds by competing with the cash crop for nutrients, water, and light.

Marigold seeds generally are purchased for ornamental purposes and typically are expensive. It may be very costly to purchase enough seeds to use marigold as a cover crop for nematode suppression, especially when the lack of direct return from using marigold as a rotation crop is considered. Some marigold varieties used in poultry feed are less expensive, but the cost can be high for a large-scale planting. However, marigold plants produce a large number of seeds that can easily be harvested from mature plants. This allows growers to readily produce their own marigold seed supply.

Another potentially negative aspect of growing marigold is that the seeds are plentiful at maturity, readily self-reseeding, light, and easily wind-blown. This can be a problem for those who don't want the marigold to spread to other areas.

Recommendation for marigold as a cover crop for nematode suppression

Marigold can conveniently be grown as part of a multicrop system, rotated or grown as an intercrop with other plants. In these cases, marigold should be seeded to obtain a high plant population and grown for its full vegetative growth period, at the end of which it can be incorporated into the soil as a green manure, thereby increasing soil organic matter. *Tagetes erecta* 'Cracker Jack' or *T. patula* 'Single Gold' may be sown at 20 plants/m^2 (either broadcast or seeded in rows). A marigold cover crop can be grown for two to four months during the summer season, most timely period being right after termination of a spring vegetable crop. If thrips are potentially problematic, the marigold crop should be terminated before it fully blooms to avoid thrips build-up. Marigold may also be interplanted, but growing it in rotation has advantages. Marigold intercrops can reduce vegetable crop yields because of the need to set aside some of the field for growing marigold. Also, competition with the vegetable crop can cause some yield reduction. However, growers can consider intercropping banana and marigold due to the wide spacing in a banana planting system. After planting, marigolds should be irrigated by drip irrigation or through low-pressure sprinkler heads, as high-pressure irrigation may prevent young plants from fully establishing.

Conclusion

As registered chemical nematicides continue to become more limited in availability, it will be necessary to develop other management strategies for plant-parasitic nematodes. Most synthetic nematicides are expensive and because of their toxicity have adverse effects on non-target organisms, such as beneficial soil microorganisms. The negative aspects of soil fumigants and nematicides and the increasing demand for organic produce and less environmentally harmful agricultural practices make marigold a potentially valuable alternative to chemical nematicides for nematode management.

It is clear that marigold can be used as a substitute for synthetic nematicides. In some instances, marigold can reduce nematode populations at greater soil depths than soil fumigation. In addition, marigold is more environmentally friendly than chemical nematicides because it does not repress other soil microorganisms. However, to successfully incorporate marigold into an integrated nematode management program it is important to select a marigold variety that is effective against the locally occurring nematode populations.

Currently, researchers in Hawai‘i, Florida, and California are evaluating sunn hemp, marigold, and cowpea for their ability to reduce the occurrence of aphid-borne non-persistent viruses and suppress weed, insect, and nematode pests directly through modification of the cropping environment and enhancement of beneficial organisms. We believe that to optimize their use in integrated pest management programs, cover crops should not be used solely to mitigate problems caused by plant-parasitic nematodes, but rather used simultaneously to help suppress multiple pest organisms and provide other benefits to a farming operation.

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