# Using trap crops to manage plant parasitic nematodes on vegetable crops

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***Abstract***

**Trap cropping is a nematode management technique that has been tested periodically since the late 1800s. A susceptible host is planted, and larvae of a sedentary parasitic nematode, such as root-knot, are induced to enter and establish a feeding site. Once this has occurred, and the female begins to mature, it is unable to leave the root. The plants are then destroyed before the life cycle of the nematode can be completed, trapping nematodes within the root. A harvestable crop is planted after termination of the trap crop. A field trial was conducted using six different trap crops (carrot, beans, sesame, sugar beet, tomatoes, and resident weeds) in a field infested with root knot nematode (*Meloidogyne javanica*). The trap crops were destroyed at three weeks after planting, either by tillage, by an application of herbicide, or both; followed by planting a harvestable crop of carrots. A second trial utilized carrots as the trap crop, followed by a harvestable crop of carrots. The carrot trap crop was destroyed at 3, 4 or 5 weeks after planting with or without the addition of a biological nematicide. In both trials, the trap crop treatments were compared to an untreated control (dry fallow) and a standard fumigant treatment. In both trials, several treatments yielded marketable carrots or reductions in root-knot nematode populations that were comparable to the chemical standard, and significantly better than the untreated ($P$=0.05), validating the potential of trap cropping for managing sedentary plant-parasitic nematodes on vegetable crops.**

**Keywords:** root-knot nematode, *Meloidogyne* sp., trap crop, carrots, *Daucus carota* subsp. *sativus*

## INTRODUCTION

Trap cropping is a nematode management technique that has been tested periodically since the late 1800s (Thorne, 1961). A susceptible host is planted and larvae of a sedentary parasitic nematode such as root-knot are induced to enter and establish a feeding site. Once this has occurred, and the female begins to mature, it is unable to leave the root. The plants are then destroyed before the life cycle of the nematode can be completed, trapping nematodes within the root. The potential for loss of registration of chemical nematicides for various environmental reasons is great enough that the development of an IPM approach using trap crops alone, or trap crops plus a biological nematicide to control nematode populations is warranted (Westerdahl et al., 1997).

Root-knot nematodes (*Meloidogyne* spp.) are widely distributed throughout the world and are a major problem on many annual vegetable crops. About 85% of the USA carrot production and 28% of tomato production is in California (McGiffen et al., 1997). In California, for example, root-knot nematodes are the most important nematode pest of tomatoes (*Lycopersicon esculentum*) and carrots (*Daucus carota*) (UC IPM Online, 2013, 2016). In addition, stubby root nematode (*Paratrichodorus* spp.) is found statewide on carrots, often in association with root-knot nematode, and needle nematode (*Longidorus africanus*) is an important pest on carrots in the Imperial Valley (UC IPM Online, 2016).

Current control methodology relies on the use of Metam products, and 1,3-dichloropropene (1,3-D, Telone II). Metam sodium, for example, was used on 33% of California's carrot acreage in 1997, and 1,3-D was used on 10%. Although methyl bromide is no longer registered on carrots, it was used on 1% of California's carrot acreage in 1997

(approximately 5,000 acres). In 1996, 47,000 acres of tomatoes in the US were treated with methyl bromide (Crop Profile for Carrots in California Online, 2000).

For some situations, root-knot nematode resistant tomatoes are available, and root-knot nematode resistant carrots are being developed. Even when nematode resistant crops are available, there is still a need for other control methods. In the past, for example, continuous planting of nematode resistant cultivars has led to a selection of resistance breaking races, so a rotation with susceptible cultivars will continue to be advisable (Kaloshian et al., 1996).

**MATERIALS AND METHODS**

Two field trials utilizing carrots (*Daucus carota* subsp. *sativus*) as an indicator crop for root-knot nematode damage to vegetables were conducted at the University of California South Coast Research and Extension Center in Orange County, CA, USA, in a field with an established population of root-knot nematode (*Meloidogyne javanica*). Each trial had 20-treatments, and each treatment consisted of five replicates in a randomized complete block design. Single row plots were 4.3 m long plus a 0.91-m buffer on either end, and 0.76 m wide. The field location had a loam soil (66% sand, 21% silt, 13% clay and 0.6% stable organic matter) with a pH of 7.6 and a CEC of 0.68 milimhos$^{-1}$. The previous crop was sugar beets (*Beta vulgaris*).

The first trial tested six different trap crops: 1) carrot (*Daucus carota* subsp. *sativus*), 2) beans (*Phaseolus vulgaris*), 3) sesame (*Sesamum indicum*), 4) sugar beets (*Beta vulgaris* subsp. *vulgaris*), 5) tomatoes (*Lycopersicon esculentum*), and 6) resident weeds (wet fallow). The trap crops were destroyed at three weeks after planting either by tillage, by an application of glyphosate (Roundup Herbicide, Monsanto), or both tillage and glyphosate, so that there were three treatments with each trap crop for a total of 18 treatments. Following destruction of the trap crops, a harvestable crop of carrots was planted. The trap crop treatments were compared to an untreated control (dry fallow), and a standard fumigant treatment of 1,3-dichloropropene (1,3-D, Telone II, Dow Agrosciences) at 84.2 L ha$^{-1}$ bringing the total treatments to 20 (Table 1). 1,3-D was applied the same day the trap crops were planted. Seeded plots and wet fallow treatments were watered daily or every other day as needed to maintain required moisture for germination and growth. Wet fallow consisted of irrigation to germinate weeds naturally present in the field. The dry fallow treatment did not receive irrigation.

The second trial utilized carrots both as a trap crop and as a subsequent harvestable crop. In addition, wet fallow (resident weeds) was again tested for its potential to serve as a trap crop. The trap crops were destroyed at 3, 4, or 5 weeks after planting with or without the addition of the biological nematicide Ditera (*Myrothecium verrucaria*, Valent) at 56 kg ha$^{-1}$ (Table 2). Glyphosate treatments were conducted either 3 (Glyphosate3) or 4 weeks (Glyphosate4) following planting. Tillage treatments were conducted either at 3 (tillage3), 4 (tillage4), or 5 weeks (tillage5) after planting. Ditera treatments were applied just prior to planting the harvestable carrot crop. As in the first trial, the trap crop treatments were compared to an untreated control (dry fallow), and a standard fumigant treatment of 1,3-dichloropropene at 84.2 L ha$^{-1}$ bringing the total treatments to 20. 1,3-D was applied the same day the trap crops were planted. Seeded plots and wet fallow treatments were watered daily or every other day as needed to maintain required moisture for germination and growth.

Trials were sampled for nematodes pre-plant to establish the level of the population, and at harvest. Soil samples consisted of 12, 2.5-cm diameter cores per replicate to a 30 cm depth. Nematode extraction was by elutriation followed by sugar centrifugation (Byrd et al., 1976). Harvested carrots were graded into 4 categories: 1) marketable without nematode damage, 2) marketable with nematode damage, 3) not marketable with nematode damage, and 4) not marketable without nematode damage. Carrots in each category were counted and weighed. For data analysis, categories 1 and 2 were combined to determine marketable carrots. Data were analyzed with analysis of variance (ANOVA) followed by Fisher's least significant difference test. Percent values were arcsin transformed prior to analysis.

Table 1. Yield and nematode data for first trap crop trial.

| Treatments | Percent marketable carrots[a] | | Root-knot nematode $L^{-1}$ soil |
|---|---|---|---|
| | Based on number | Based on weight (kg) | |
| Dry fallow + tillage | 10.5 abc | 11.5 abcde | 2290 e |
| Dry fallow + glyphosate | 24.1 cde | 20.2 efg | 1820 de |
| Dry fallow + 1,3-D + tillage | 44.1 f | 58.9 h | 300 a |
| Wet fallow + tillage | 15.1 abcd | 12.4 abcdef | 1380 bcde |
| Wet fallow + glyphosate | 3.8 a | 3.1 ab | 880 abcd |
| Sesame + tillage | 30.9 ef | 30.9 g | 1320 abcde |
| Sesame + glyphosate | 10.0 abc | 3.1 ab | 1400 bcde |
| Sesame + glyphosate + tillage | 10.1 abc | 12.9 abcdef | 1000 abcd |
| Carrot + tillage | 27.2 de | 25.5 fg | 1130 abcd |
| Carrot + glyphosate | 11.7 abc | 10.1 abcde | 630 ab |
| Carrot + glyphosate + tillage | 15.1 abcd | 6.7 abcde | 750 abc |
| Beans + tillage | 20.4 bcde | 19.2 defg | 1310 abcde |
| Beans + glyphosate | 3.8 a | 4.0 ab | 580 ab |
| Beans + glyphosate + tillage | 8.3 ab | 7.8 abcde | 1350 abcde |
| Sugar beet + tillage | 12.9 abcd | 18.4 cdefg | 1760 cde |
| Sugar beet + glyphosate | 2.5 a | 0.6 a | 640 ab |
| Sugar beet + glyphosate + tillage | 12.0 abc | 13.3 abcdef | 910 abcd |
| Tomatoes + tillage | 14.5 abcd | 16.6 bcdef | 1730 cde |
| Tomatoes + glyphosate | 5.4 a | 5.2 abc | 600 ab |
| Tomatoes + glyphosate + tillage | 9.6 ab | 5.9 abcd | 710 abc |

[a]Percents were subjected to arcsin transformation prior to analysis. Non-transformed means are shown. Each figure is the mean of 5 replicates. Means not followed by the same letter are significantly different from each other according to Fisher's protected least significant difference test at *P=0.05*.

Table 2. Yield and nematode data for second trap crop trial.

| Treatments | Percent marketable carrots[a] | | Root-knot nematode $L^{-1}$ soil |
|---|---|---|---|
| | Based on number | Based on weight (kg) | |
| Dry fallow + glyphosate4 + tillage5 | 15.4 a | 26.6 ab | 390 a |
| Dry fallow + 1,3-D + tillage4 | 19.6 abc | 39.8 bcd | 10 e |
| Dry fallow + tillage4 + Ditera | 18.8 ab | 43.2 bcd | 410 a |
| Wet fallow + glyphosate3 | 25.6 abc | 36.6 abcd | 160 bcd |
| Wet fallow + glyphosate3 + tillage4 | 24.8 abc | 43.2 bcd | 150 ab |
| Wet fallow + glyphosate3 + tillage4 + Ditera | 25.8 abc | 49.8 cd | 280 abc |
| Wet fallow + glyphosate4 | 21.0 abc | 26.6 abc | 100 de |
| Wet fallow + glyphosate4 + tillage5 | 19.4 abc | 34.8 abcd | 430 a |
| Carrot + glyphosate3 | 30.6 bc | 43.2 bcd | 130 abc |
| Carrot + glyphosate3 + tillage4 | 21.8 abc | 46.6 bcd | 770 ag |
| Carrot + glyphosate3 + tillage4 + Ditera | 27.4 abc | 39.8 bcd | 330 a |
| Carrot + glyphosate3 + Ditera | 28.2 abc | 50.0 cd | 90 cd |
| Carrot + glyphosate4 | 24.8 abc | 16.6 a | 150 abc |
| Carrot + glyphosate4 + tillage5 | 19.8 abc | 26.4 ab | 190 abc |
| Carrot + glyphosate4 + tillage5 + Ditera | 25.8 abc | 34.8 abcd | 540 a |
| Carrot + glyphosate4 + Ditera | 19.0 abc | 36.6 bcd | 170 ab |
| Carrot + tillage3 | 34.2 c | 53.4 d | 480 a |
| Carrot + tillage3 + Ditera | 27.4 abc | 36.6 bcd | 250 abc |
| Carrot + tillage4 | 21.0 abc | 41.6 bcd | 390 a |
| Carrot + tillage4 + Ditera | 32.0 bc | 50.0 d | 520 a |

[a]Percents were subjected to arcsin transformation prior to analysis. Nontransformed means are shown. Each figure is the mean of 5 replicates. Means not followed by the same letter are significantly different from each other according to Fisher's protected least significant difference test at *P=0.05*.

## RESULTS

In the first trial, dry fallow + 1,3-D + tillage, sesame + tillage, and carrot + tillage provided an increase in the percent marketable carrots based on either number of carrots or weight of carrots compared to the untreated ($P$=0.05, Table 1). Dry fallow + glyphosate, and carrot + glyphosate + tillage were significant at $P$=0.10 (data not shown). Overall, numerically, 11 treatments based on number of percent marketable carrots, and 10 treatments based on weight of percent marketable provided an increase in yield over the untreated control. Numerically, all treatments had fewer root-knot nematode juveniles in soil at harvest than the untreated control. At $P$=0.05, the following 11 treatments had fewer root-knot nematode juveniles in soil at harvest than the untreated control: dry fallow + 1,3-D + tillage, wet fallow + glyphosate, sesame + glyphosate + tillage, carrot + tillage, carrot + glyphosate, carrot + glyphosate + tillage, beans + glyphosate, sugar beet + glyphosate, sugar beet + glyphosate + tillage, tomatoes + glyphosate, and tomatoes + glyphosate + tillage.

In the second trial, numerically, all treatments had a greater percentage of marketable carrots based on number of carrots harvested than the untreated control (Table 2). At $P$=0.05, carrot + glyphosate3, carrot + tillage3, and carrot + tillage4 + Ditera had a greater percentage of marketable carrots based on number of carrots harvested than the untreated control. Numerically, all treatments except wet fallow + glyphosate4, and carrot + glyphosate4 had a greater percentage of marketable carrots based on weight than the untreated control. At $P$=0.05, wet fallow + glyphosate3 + tillage4 + Ditera, carrot + glyphosate3 + Ditera, carrot + tillage3, and carrot + tillage4 + Ditera had a greater number of marketable carrots based on weight than the untreated control. At $P$=0.10, dry fallow + tillage4 + Ditera, wet fallow + Glyphosate3 + tillage4, Carrot + Glyphosate3, and Carrot + Glyphosate3 + tillage4 had a greater percentage of marketable carrots based on weight than the untreated control (data not shown). Numerically, 11 treatments had fewer root-knot nematode juveniles in soil at harvest than the untreated control. At $P$=0.05, dry fallow + 1,3-D + tillage4, wet fallow + glyphosate3, wet fallow + glyphosate4, and carrot + glyphosate3 + Ditera had fewer root-knot nematode juveniles in soil at harvest than the untreated control.

## DISCUSSION AND CONCLUSIONS

In the first trial that tested the efficacy of six different trap crops, carrot and sesame were the most successful treatments, based on yield of marketable carrots. Each of the trap crops tested, provided significant nematode control in one or more treatments (Table 1). Carrot was the only crop to provide significant nematode control in all three treatments in which it was tested. Because of this, carrot was selected for further testing in the second trial. Further testing of potential trap crop species beyond the scope of this trial could reveal crops that would provide better control of root-knot and other nematodes than carrots.

Results of the second trial further demonstrate the potential of trap cropping as a management tool, but are more difficult to interpret. It is impressive that all treatments, including wet fallow treatments that utilized weeds present in the field as a trap crop, had yields numerically superior to the untreated control with respect to percent marketable yield based on number of carrots (Table 2). In addition, all but two treatments were numerically superior to the untreated control with respect to percent marketable yield based on weight of carrots harvested. Crop termination at 3 weeks appeared to be more successful than termination at 4 weeks based on number of treatments that significantly increased yields over the untreated control ($P$=0.05). For treatments terminated at 4 weeks, the only one to significantly increase yields included a Ditera application at planting of the final carrot crop. This could indicate that for the growing area in which the trials were conducted, that by four weeks after planting, nematode development had proceeded past the critical time for crop termination. Other than the standard nematicide treatment, the four treatments that provided significant nematode control ($P$=0.05) included two wet fallow treatments with glyphosate at either 3 or 4 weeks after planting, and carrot plus glyphosate at 3 weeks plus Ditera. This indicates that further testing of the wet fallow treatments is warranted, combined with developing an understanding of the root-knot nematode susceptibility of weeds present in fields in which the technique is used.

The timing of crop termination is critical for the success of trap cropping. These trials have demonstrated that the technique can be used successfully for nematode management, but the technique should be further refined with the use of nematode degree-day calculations in the location in which it will be used (Noling and Ferris, 1987; UC IPM Online, N.D.). Nematodes develop more rapidly in warmer than in cooler soil. Therefore, a warmer carrot growing area would require earlier crop termination for successful nematode control than a cooler area. Because trap crops must be terminated just a few weeks after planting in order to prevent maturation of nematodes within roots, the trap crop itself is not of economic value either for yield or for biomass.

This management tool, as well as others not utilizing fumigants, highlights the importance of accurately knowing the species of nematode present in a given field in order to be successful. Theoretically, trap cropping is not expected to be successful for managing species of ectoparasitic or migratory endoparasitic nematodes that might be found in vegetable crop fields either alone, or in combination with root-knot nematode. Trap cropping will not solve all nematode problems in fields with mixed genera of nematodes such as carrot fields with populations of the ectoparasites stubby root and needle nematode. Recently developed molecular identification techniques can be of value in the implementation of trap cropping (Kaloshian et al., 1996).

The cost of a new management technique is always an issue. Trap cropping requires irrigation to grow the trap crop, or to germinate nematode susceptible weeds. This plus the cost of trap crop seeds, planting the seeds, and crop termination are the major expenses. It should be noted that the major chemical control methodologies currently in use on vegetable crops in California, USA require the use of irrigation, either as part of the application process as in water applications of metam products, or to seal the soil surface to minimize emissions. Therefore, the cost of irrigation needed for trap cropping might be similar to that for a fumigant nematicide application and, overall, less costly than the fumigant application. Germinating weeds followed by timely crop termination prior to development of seeds, also provides the benefits of weeds control and no additional cost. Overall, the results of the current trials indicate that trap cropping can be a valuable management tool for root-knot nematode on vegetable crops on which this nematode is an important pest.

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