Evaluation of trap cropping for management of root-knot nematode on annual crops

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Abstract

In trap cropping, a 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, she is unable to leave the root. The plants are then destroyed before egg-laying by nematodes is initiated, trapping nematodes within the root. Two field trials were conducted in subsequent years in a field with an established population of root-knot nematode (*Meloidogyne javanica*). Each trial consisted of 20 treatments, with five replicates of each treatment in a randomized complete block design. Treatments were either carrots planted as a trap crop, wet fallow as a trap crop (irrigation to germinate weeds), dry fallow (untreated control), or standard chemical (1,3-Dichloropropene). Eight treatments were identical in the two trials. The other treatments differed by date of crop termination. In Trial 1, trap crops were terminated at either three or four-weeks following planting. In Trial 2, termination was at either two or three weeks following planting. Following termination of the trap crops, all treatments were planted to carrots. Some of the treatments were treated at planting with a biological nematicide (DiTera). Compared to the untreated control, a number of the other treatments demonstrated a greater percentage of marketable carrots and a reduction in the level of root-knot nematodes at harvest. These results indicate that either planting a trap crop or that a pre-irrigation to germinate weeds could provide a degree of nematode control. A trap crop can be any root-knot nematode susceptible seed. Carrots were selected based on results of previous trials comparing potential trap crops. Carrots were also used as the final "commercial" demonstration crop because they are a sensitive root-knot nematode bioindicator crop. Results from carrots could be extended to other root-knot sensitive 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, she is unable to leave the root. The plants are then destroyed before the life cycle of the nematode can be completed, trapping the 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* sp.) are widely distributed throughout the world and are a major problem on many annual vegetable crops. About 83% of the USA carrot production is in California (McGiffen et al., 1997). In California, root-knot nematodes are the most important nematode pest of carrots (*Dacus carotae*) (UC IPM Online,

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2016). In addition, the stubby root nematode (*Paratrichodorus* sp.) is found statewide on carrots often in association with the root-knot nematode and the needle nematode (*Longidorus africanus*) and 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). 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 4% of California's carrot acreage in 1996 (Crop Profile for Carrots in California Online, 2000).

For some situations, root-knot nematode-resistant crops, such as tomatoes, are available, and root-knot nematode-resistant carrots are being developed. Even when nematode-resistant crops are available, there will still be 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 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 with a 0.91 m buffer on both ends, 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 (cation-exchange capacity) CEC of 0.68 millimhos^{-1}. The previous crop was sugar beets (*Beta vulgaris*).

Treatments were either carrots planted as a trap crop, wet fallow as a trap crop (consisting of irrigation to germinate weeds naturally present in the field), dry fallow (an untreated control that did not receive irrigation), or standard chemical 1,3-D (Telone II, Dow AgroSciences, Indianapolis, IN, USA) at 84.2 L ha^{-1}. Trap crops were terminated at three or four weeks following planting in the first trial or two or three weeks following planting in the second trial. The crops were terminated either by tillage, by an application of Glyphosate (Roundup Herbicide, Monsanto, St. Louis, MO, USA), or both. Six treatments in which Glyphosate was applied at three weeks after planting were the same in both trials. Two additional treatments: carrot + tillage3 and carrot + tillage3 + DiTera were also included in both trials. Following termination of the trap crops, all treatments were planted to carrots. Some of the treatments were treated at planting with a biological nematicide DiTera (*Myrothecium verrucaria*, Valent, Libertyville, IL, USA) at 56 kg ha^{-1}. In both trials, 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 twelve 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 four 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 (JMP). Percent values were arc/sin transformed prior to analysis.

In the first trial, Glyphosate treatments were conducted either three (Glyphosate3) or four weeks (Glyphosate4) following planting (Table 1). Tillage treatments were conducted either at three (tillage3), four (tillage4), or five weeks (tillage5) after planting. DiTera treatments were applied just prior to planting the carrot indicator crop. The first trial consisted of the 20 treatments shown in Table 1.

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

Treatments (numbers indicate weeks post-planting)	Marketable carrots (%)[a]				Root-knot nematode L^{-1} soil	
	Based on numbers		Based on weight (kg)			
Untreated control (dry fallow + Glyphosate4 + tillage5)	26.4[b]	abc[c]	22.8	bcd	12,720	f
Standard chemical (dry fallow + 1,3-D + tillage4)	43.0	c	34.5	d	814	a
Dry fallow + tillage4 + DiTera	25.2	abc	20.9	abcd	4680	bcd
Wet fallow + Glyphosate3	35.4	abc	26.7	cd	3340	abcd
Wet fallow + Glyphosate3 + tillage4	39.7	abc	27.2	cd	4174	abcd
Wet fallow + Glyphosate3 + tillage4 + DiTera	28.5	abc	24.5	bcd	6030	de
Wet fallow + Glyphosate4	29.3	abc	22.3	abcd	3010	abcd
Wet fallow + Glyphosate4 + tillage5	12.9	a	11.4	abc	4240	abcd
Carrot + Glyphosate3	21.1	abc	14.3	abc	4710	bcd
Carrot + Glyphosate3 + tillage4	35.4	abc	22.0	abcd	5040	cde
Carrot + Glyphosate3 + tillage4 + DiTera	36.8	abc	17.9	abc	1510	abc
Carrot + Glyphosate3 + DiTera	32.7	abc	21.3	abcd	1320	ab
Carrot + Glyphosate4	16.4	ab	14.4	abc	2270	abc
Carrot + Glyphosate4 + tillage5	22.6	abc	13.1	abc	1660	abc
Carrot + Glyphosate4 + tillage5 + DiTera	24.9	ab	12.9	ab	2360	abc
Carrot + Glyphosate4 + DiTera	18.1	a	10.2	a	1550	abc
Carrot + tillage3	38.0	abc	23.2	abcd	3988	abcd
Carrot + tillage3 + DiTera	41.9	bc	24.5	bcd	8490	e
Carrot + tillage4	37.3	abc	23.0	abcd	2720	abcd
Carrot + tillage4 + DiTera	34.3	abc	16.2	abc	2130	abc

[a]Percentages were subjected to arcsin transformation prior to analysis. Nontransformed means are shown.

[b]Each figure is the mean of five replicates.

[c]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.

In the second trial, Glyphosate treatments were conducted either two (Glyphosate2) or three weeks (Glyphosate3) following planting (Table 2). Tillage treatments were conducted either at two (tillage2), three (tillage3), or four weeks (tillage4) after planting. DiTera treatments were applied just prior to planting the carrot indicator crop. The second trial consisted of the 20 treatments presented in Table 2.

RESULTS

In the first trial, no treatments had a greater percentage of marketable carrots based on either number or weight of carrots. Numerically, the following six treatments had a greater percentage of marketable carrots than the untreated control (dry fallow + Glyphosate4 + tillage5; based on number and on weight of carrots): dry fallow + 1,3D + tillage4; wet fallow + Glyphosate3; wet fallow + Glyphosate3 + tillage4; wet fallow + Glyphosate3 + tillage4 + DiTera; carrot + tillage3; and carrot + tillage3 + DiTera. In addition, numerically, the following six treatments had a greater percentage of carrots than the untreated control (based on number of carrots): wet fallow + Glyphosate4; carrot + Glyphosate3+ tillage4; carrot + Glyphosate3 + tillage4 + DiTera; carrot + Glyphosate3 + DiTera; carrot + tillage4; and carrot + tillage4 + DiTera. Based on number of carrots, increases over the untreated control ranged from 2.1-15.5% for trap crop treatments compared to 16.6% for the standard chemical treatment. Based on weight of carrots, increases over the untreated control ranged from 0.2-4.4% compared to 11.7% for the standard treatment. At P=0.05, all treatments had fewer root-knot nematode juveniles in soil at harvest than the untreated control. Reductions in the number of root-knot juveniles in soil at harvest for trap crop treatments ranged from 33.3-89.6% compared to 93.6% for the standard chemical treatment.

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

Treatments (numbers indicate weeks post-planting)	Marketable carrots (%)[a]				Root-knot nematode L^{-1} soil	
	Based on numbers		Based on weight (kg)			
Untreated control (dry fallow + Glyphosate3 + tillage4)	10.1[b]	a[c]	17.0	a	93.0	d
Standard chemical (dry fallow + 1,3-D + tillage3)	55.1	cd	74.1	de	3.0	a
Dry fallow + tillage3 + DiTera	41.4	bcd	57.2	bcde	94.3	d
Wet fallow + Glyphosate2	33.1	bcd	53.9	bcde	17.8	abc
Wet fallow + Glyphosate2 + tillage3	50.0	cd	70.5	cde	50.8	abcd
Wet fallow + Glyphosate2 + tillage3 + DiTera	37.9	bcd	53.5	bcde	58.5	bcd
Wet fallow + Glyphosate3	16.3	ab	41.0	bc	61.5	cd
Wet fallow + Glyphosate3 + tillage4	39.9	bcd	47.6	bcd	17.3	abc
Carrot + Glyphosate2	37.9	bcd	52.8	bcde	17.8	abc
Carrot + Glyphosate2 + tillage3	62.7	d	76.8	e	23.0	abc
Carrot + Glyphosate2 + tillage3 + DiTera	53.5	cd	68.7	cde	36.0	abc
Carrot + Glyphosate2 + DiTera	36.9	bcd	52.8	bcde	64.0	cd
Carrot + Glyphosate3	29.0	abc	45.6	bcd	21.0	abc
Carrot + Glyphosate3 + tillage4	33.5	bcd	46.3	bcd	17.3	abc
Carrot + Glyphosate3 + tillage4 + DiTera	21.9	ab	35.4	ab	18.0	abc
Carrot + Glyphosate3 + DiTera	40.1	bcd	58.6	bcde	20.5	abc
Carrot + tillage2	18.0	ab	30.1	ab	10.0	a
Carrot + tillage2 + DiTera	24.3	abc	42.1	bc	10.8	ab
Carrot + tillage3	43.8	bcd	59.7	bcde	10.0	a
Carrot + tillage3 + DiTera	31.7	bcd	41.4	bc	19.8	abc

[a]Percentages were subjected to arcsin transformation prior to analysis. Nontransformed means are shown.

[b]Each figure is the mean of five replicates.

[c]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.

In the second trial, numerically, all treatments had a greater percentage of marketable carrots based on both number and weight of marketable carrots than the untreated control. At P=0.05, all treatments except: wet fallow + Glyphosate3; carrot + Glyphosate3; carrot + Glyphosate3 + tillage4 + DiTera; carrot + tillage2; and carrot + tillage2 + DiTera had a greater percentage of marketable carrots based on number than the untreated control. At P=0.05, all treatments except carrot + Glyphosate3 + tillage4 + DiTera and carrot + tillage2 had a greater percentage of marketable carrots based on weight than the untreated control. Numerically, all treatments except dry fallow + tillage3 + DiTera had a lower level of root-knot juveniles in soil at harvest than the untreated control. At P=0.05, all treatments except dry fallow + tillage3 + DiTera; wet fallow + Glyphosate2 + tillage3; wet fallow + Glyphosate2 + tillage3 + DiTera; wet fallow + Glyphosate3; and carrot + Glyphosate2 + DiTera had fewer root-knot juveniles in soil at harvest than the untreated control. Based on the number of carrots, increases over the untreated control ranged from 6.1-27.8% for trap crop treatments compared to 45.0% for the standard chemical treatment. Based on weight of carrots, increases over the untreated control ranged from 13.1-59.7% compared to 57.1% for the standard treatment. Reductions in the number of root-knot juveniles in soil at harvest for trap crop treatments ranged from 31.2-89.3% compared to 96.8% for the standard chemical treatment.

DISCUSSION AND CONCLUSIONS

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 the number of carrots. This indicates that further testing of the wet fallow treatments is warranted, combined with developing a better 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; http://ipm.ucanr.edu/WEATHER/ddconcepts.html). Nematodes develop more rapidly in warmer than in cooler soil. Therefore, a warmer carrot growing area would require earlier trap crop termination for successful nematode control than a cooler area.

Root-knot nematode requires approximately 600 degree-days over 10°C to complete one generation (Ferris et al., 1985). Based on soil temperature data collected at a the CIMIS weather station located on the research station (http://ipm.ucanr.edu/WEATHER/index.html), for the two years during which the trials were conducted, degree-day accumulation varied by only a few degrees each week while the trap crops were in the ground: week 2 (242 in Trial 1 vs. 244 Trial 2), week 3 (360 vs. 366), week 4 (482 vs. 489), and week 5 (608 vs. 611). Following the planting of the final carrot crop, degree-day accumulation from planting to harvest was greater for the first trial (2321) than for the second trial (1591). This difference in degree-day accumulation would account for approximately 1.2 more generations in the first trial. Root-knot nematode populations have been shown to increase at an exponential rate during growing season, and this difference in number of generations helps to explain the relatively large differences in final populations between the two trials.

In the first trial, several trends appear for both the number and weight of marketable carrots. Termination of wet fallow by Glyphosate worked better at thee than at four weeks and adding tillage at four weeks but not at five weeks resulted in an additional increase in yield. The addition of DiTera did not improve yields. When carrot was used as a trap crop, and the only difference between treatments was time of crop termination, in 11 out of 12 comparisons, yields were greater with termination at three than at four weeks. Tillage treatments alone (with or without DiTera) were consistently better than Glyphosate treatments alone (with or without DiTera). In some treatments, addition of DiTera improved yields, but not consistently.

In the second trial, termination of wet fallow by Glyphosate worked better at two than at three weeks and adding tillage at both three and four weeks resulted in an additional increase in yields. The addition of DiTera did not improve yields. When carrot was used as a trap crop, and the only difference between treatments was time of crop termination with Glyphosate, in six out of eight comparisons yields were greater with termination at two than at three weeks. In contrast to trial 1, when crops were terminated by tillage alone, in three out of four comparisons, yields were greater with termination at three than at two weeks. In addition, in contrast to trial 1, Glyphosate treatments alone (with or without DiTera) were better than tillage treatments alone (with or without DiTera) in six out of eight comparisons. As in trial 1, in some treatments, addition of DiTera improved yields, but not consistently.

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 the 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 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 at 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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