CALIFORNIA FRESH CARROT ADVISORY BOARD
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Project title Novel Management Tools Against Root-knot Nematodes in California Fresh Carrot Production

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Introduction

California fresh market carrots were harvested from 74,200 acres in 2014 (1). The harvest supplied approximately 85% of the US market. Root-knot nematodes (*Meloidogyne* spp.) (2, 3) are the main plant pathogens in California carrot production with a conservative estimate of 5% production loss despite current use of various soil fumigants (4). Besides direct yield reductions, root-knot nematode damage reduces the quality of the harvested product due to galling and root forking. Root deformations can significantly lower the marketable yield. The wide host range of these nematodes makes crop rotation alone nearly impossible. Currently, management of the nematodes relies primarily on use of the soil-fumigants 1,3-dichloropropene, metam-sodium or metam-potassium. In 2013 these products were applied to about 12%, 9% and 19%, respectively of California's carrot acreage (5). The latter two methyl isothiocyanate-releasing compounds also include uses against other targets such as some weeds and fungal soilborne pathogens (6).

In 2013, approximately 13,000 acres in the Imperial County were treated with the biological control product MeloCon (a.i. *Purpureocillium lilacinum* [syn. *Paecilomyces lilacinum*]) as metam-sodium use was not permitted (7). Still, in the absence of resistant carrot cultivars, effective biological or chemical non-fumigant nematicides, approximately 40% of California's carrot acres are fumigated. There is considerable interest by stakeholders (8) and regulatory agencies to reduce applications of these fumigants (9).

The objective of this project was to evaluate the efficacy of three novel non-fumigant nematicides (Nimitz, Dp1 and Dp3) against Southern root-knot nematodes (rkn, *Meloidogyne incognita*) in carrots. These products are still in the later stages of development although Nimitz (previously MCW-2, a.i. fluensulfone) is already registered in flowering vegetables. Carrot production is expected to be one of the next market segments targeted. This was the first year we tested two granule formulations in addition to the standard EC formulation. A liquid formulation of Dp1 had shown excellent activity in previous rkn-infested carrot trials. In addition, we evaluated a granular formulation of Dp1 this season.

Materials and Methods:

Trials were conducted at the UC South Coast Research and Extension Center (UC SCREC), Irvine, CA and at the Shafter Research Farm, Shafter, CA. The soil at the trial site was a San Emigdio sandy loam with 17% clay, 63% sand and 20% silt, 0.2% OM, pH 7.9. The test site at SCREC is infested with the Southern rkn *M. incognita*. For the past several years at least one rkn-host crop has been grown during summer to keep the pathogen population at a high level. During the winter the field was cropped to rkn-susceptible wheat (cv. Yecoro Rojo). The trial was designed as a randomized complete block with 5 replications. Each individual plot was 10 ft long and 2 ft wide. At the beginning (May 28, 2015) (P*i*) and harvest (September 21, 2015)(P*f*) of the trial, six soil cores were taken to a depth of 10 inches from each plot and pooled. A subsample was extracted by incubation on Baermann funnels for 5 days at 26˚C. Second-stage juveniles (J2) of rkn were enumerated under 40x magnification. Reported are the recovered J2; the data were not adjusted for extraction efficacy. The extraction efficacy with SCREC soil for 5 day incubation on Baermann funnels at 26˚C is typically between 35 - 40%. Two weeks before seeding, treatments with Nimitz (Tab. 1, treatment #3, #4 and #10) were suspended in 2 gallons water, applied with a sprinkler can in a 1.65 ft band and rototilled into the top 4 inches. An additional 2 gallons water was then sprinkled on top of each plot as well as 9 days before seeding. The additional water was recommended by the manufacturer to avoid potential phytotoxicity problems particularly with seeded crops. Dp1 gr was formulated as a granule that was applied 9 days before seeding (treatment #9). The granules were uniformly spread in a 1.65 ft band and immediately incorporated with a rototiller to approximately 4 inch depth, followed by 2 gal water via sprinkler can. The liquid Dp1 treatments (Tab. 1, #7 and #8) were suspended in 2 gallons of water, applied with a sprinkler can in a 1.65 ft band and rototilled into the top 10 cm at 3 days before planting. Dp3 (treatment #2) was suspended in 2 gallons of water, applied with a sprinkler can in a 1.65 ft band on top of the plots and incorporated into the top 4 inches by rototilling. Four weeks after seeding, treatment #2 and #10 received a second application with Dp3 suspended in 2 gallons of water and sprinkler can applied in a band over the top of the seedlings. Non-treated carrot seed (var. Imperator 58, Lockhart Seeds Inc., Stockton, CA) was seeded in a single row at approximately 0.62 g/3 m row on June 11, 2015. This cultivar is highly sensitive to rkn damage and therefore an excellent research tool for damage evaluation. After seeding, the trial was immediately sprinkler irrigated (approximately 1/2 inch). The next day, Lorox DF was applied at 1 lb/ac and Prowl H2O was used at 2 pt/ac for weed control. Soil temperatures were 21.4˚C on May 28 (Nimitz application), 22.0˚C on June 2 (Dp1 gr application), 22.2˚C on June 8 (Dp1 application), and 22.8˚C on June 11 (seeding, Dp3 application) at 6-inch soil depth. The soil surface was kept moist until emergence. The trial was fertilized on August 7 and 21 each with 50 lb/acre of 21-0-0. No insect or disease control treatments were necessary throughout the season. Plots were rated for plant vigor (0-10, worst - best) on July 8 and 15. At the second rating, height of foliar growth was measured by randomly choosing three locations within each treatment and replication and by measuring the length of the longest leaf. Seven weeks after seeding, 5 randomly chosen carrot plants per replication were carefully removed and evaluated for rkn disease symptoms (gall rating 0-10). In addition the weight of the five plants combined were taken. On August 6, eight weeks after seeding, carrot stand was determined. Due to poor overall stand, root size was very variable which made yield data meaningless. Ten randomly chosen roots were rated for rkn disease symptoms (gall rating 0-10, best-worst, Fig. 2). Carrots with root gall ratings of 4 and higher were considered non-marketable. Plant vigor and disease ratings were arcsine-transformed and nematode population data were log-transformed to normalize variances before statistical analysis. If significant, mean separation was used with Fisher's Protected LSD (P = 0.05) (SuperANOVA, Abacus, Berkeley, CA).

At the Shafter Research Farm, plots were installed on 60 inch beds by 30 ft length. The main treatment products were the same as at SCREC but included also metam sodium and MeloCon (Tab. 3). All pre-plant applications were made by watering can method on 4/2/15 except MeloCon was applied on 4/9/15. After preplant application, beds were mulched and ¼ inch water was applied. Carrots were planted on 4/9/15 with 3 seed lines per bed. Treatments listed as receiving post-plant application were treated on 5/21/15 and 6/25/15. At harvest, five random samples (approximately 1 ft of row) per plot were taken and evaluated for RKN injury (scale 0 - 10, best - worst).

Results and Discussion

The general conditions for both trials were good. The rkn population at SCREC was uniformly distributed at a moderately high level at 60 J2 per 100 cm^3 soil (Tab. 2). In Southern California the damage threshold for rkn in carrots is about one J2/100 cm^3. At the trial infestation level one would expect yield reductions of 50% or more compared to production in rkn-free soil (10). None of the treatments had obvious negative effects on carrot emergence and early development but the stand was overall thinner than in previous years. Germination of carrot seed in a moist chamber test was satisfactory with 88% and the seeding density was not different from previous years. No obviously responsible biotic or abiotic factor was detected for the less than optimal stand. One month after seeding none of the nematicide treatments appeared to be different in vigor to the non-treated control. However, by mid-July plants in all liquid nematicide treatments were taller than the control. However, at mid-season only the Dp1 treatments had lower root gall ratings than the non-treated control. There was no difference among the treatments in plant weight (data not shown). Again, the plant stand as determined in week 8 after seeding was overall rather poor and in particular in the Dp3 plots. Otherwise the crop growth was vigorous until harvest. Disease ratings at harvest revealed that root galling was mitigated in all nematicidal treatments except with Dp3 (Tab. 2, Fig. 2). Only the high rate of Dp1 was more effective than the Nimitz treatments. In terms of marketable yield, only Dp1 treatments were significantly different from the control. This was also reflected in the rkn soil population at harvest with the lowest rkn population density in the high Dp1 treatment.

The results of the Shafter trial were not useful because of a relatively low disease pressure and high variability of disease incidence. None of the treatments improved crop health in comparison to the untreated control (Tab. 3).

In summary, at SCREC Dp1 again showed very good protective activity against rkn under very high disease pressure. Both the liquid and the granular formulations look very promissing for season-long protection against rkn. Nimitz also had significant protective activity. Both granular formulations provided similar efficacy as the EC formulation. Dp3 did not sufficiently protect carrots against rkn.

Literature:

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Appendix: Tables and Figures

Tab. 1 SCREC treatment list

Trt #	Treatments[1]	Application and timing
1	Non-treated check	water only application at seeding
2	Dp3	liquid, banded split-application at 3 dbs, incorp + 28 das
3	Nimitz EC 5 pt	liquid, banded single application at 14 dbs, incorp.
4	Nimitz EC 7 pt	banded single application at 14 dbs, incorp.
5	Nimitz grA	granule, banded single application at 14 dbs, incorp.
6	Nimitz grB	granule, banded single application at 14 dbs, incorp.
7	Dp1	liquid, banded single (x) application at 3 dbs, incorp.
8	Dp1 2x	liquid, banded single (2x) application at 3 dbs, incorp.
9	Dp1 gr	granule, banded single application at 3 dbs, incorp.
10	Nimitz EC 5 pt + Dp3 x	liquid, banded single application at 14 dbs, incrop. and liquid, banded application at 28 das

Tab. 2 Summary of SCREC data

Trt #	Treatments[1]	5/28/15 pre-season J2/100 cc soil	7/8/15 seedling vigor (1st)	7/15/15 seedling height (cm)	7/30/15 mid-season gall rating*
1	NT check	75.6 ± 23.5	3.4 ± 0.87	20.0 ± 0.84 a	3.84 ± 0.99 c
2	Dp3 x+x	72.4 ± 28.1	5.0 ± 0.32	26.0 ± 0.63 cd	2.44 ± 0.50 bc
3	Nimitz EC 5 pt	62.0 ± 16.6	6.4 ± 0.51	28.0 ± 1.64 d	3.08 ± 0.85 c
4	Nimitz EC 7 pt	65.6 ± 19.5	5.0 ± 0.45	24.8 ± 1.16 bcd	3.28 ± 1.09 c
5	Nimitz grA	74.8 ± 23.1	4.8 ± 1.16	22.0 ± 1.92 ab	1.76 ± 0.56 abc
6	Nimitz grB	71.6 ± 23.3	4.0 ± 0.32	22.0 ± 1.48 ab	1.72 ± 0.68 abc
7	Dp1	38.0 ± 8.4	4.6 ± 0.68	24.2 ± 2.33 bcd	0.88 ± 0.45 a
8	Dp1 2x	48.0 ± 13.8	4.8 ± 0.37	24.2 ± 0.86 bcd	1.04 ± 0.49 ab
9	Dp1 gr	58.0 ± 16.3	4.6 ± 0.51	23.2 ± 0.66 abc	0.88 ± 0.37 ab
10	Nimitz EC 5 pt + Dp3 x	34.4 ± 12.2	4.6 ± 0.51	24.0 ± 0.89 bc	3.44 ± 0.40 c

Trt #	Treatments[1]	8/6/15 plant stand number/rep	9/21/15 harvest gall rating*	9/21/15 % marketable carrots**	*M. incognita* at harvest J2/100 cc soil
1	NT check	42.4 ± 3.47 b	7.34 ± 0.12 e	0 a	2060 ± 236 d
2	Dp3 x+x	20.0 ± 2.85 a	6.50 ± 0.11 de	0 a	596 ± 164 b
3	Nimitz EC 5 pt	63.6 ± 9.30 c	4.94 ± 0.50 bc	14 ab	632 ± 84 bc
4	Nimitz EC 7 pt	47.6 ± 4.77 bc	4.98 ± 0.64 bc	16 ab	1108 ± 142 cd
5	Nimitz grA	52.4 ± 17.34 bc	4.84 ± 0.38 bc	12 ab	576 ± 182 ab
6	Nimitz grB	43.4 ± 6.19 bc	4.50 ± 0.58 abc	20 ab	276 ± 50 a
7	Dp1	39.4 ± 5.83 ab	3.88 ± 0.47 ab	38 bc	740 ± 297 bc
8	Dp1 2x	40.2 ± 4.60 ab	3.34 ± 0.82 a	58 c	264 ± 48 a
9	Dp1 gr	41.8 ± 4.61 b	3.86 ± 0.56 ab	38 bc	388 ± 101 ab
10	Nimitz EC 5 pt + Dp3 x	39.2 ± 4.14 ab	5.54 ± 0.27 cd	4 a	532 ± 95 b

[1]Column values followed by the same letter do not differ significantly; a column with no letters indicates no significant differences among treatments (ANOVA, Fisher's Protected LSD (*P*>0.05.) Nimitz EC and grA, grB, as well as the development products Dp1, Dp1 gr and Dp3 are test compounds that currently are not registered in California carrot production.

*Root gall rating according to Zeck (1971)

** % carrots with disease rating of 3 or better

Tab. 3 Carrot disease rating at harvest at Shafter

Treatment	Nematode Gall Rating*
1. Non-treated control	2.4 BC
2. Metam sodium	3.4 AB
3. Nimitz pre-plant	2.3 C
4. Nimitz pre & Vydate 2 postplant	1.9 C
5. Dp3 pre & 2 post	1.9 C
6. Nimitz pre & Dp3 2 post	2.8 ABC
7. DP1 pre & 2 post	2.9 ABC
8. MeloCon pre at	3.5 A
Probability	0.0745
%CV	34.79
LSD $_{P=0.10}$	3.134

Fig 1 Root-knot nematode damage on carrots; rating scale 0-10, left to right.

Fig. 2 Treatment representative carrot harvest samples (9/21/2015).