# Flood irrigation applications of sodium tetrathiocarbonate reduce severity of ring nematode and bacterial canker in prunes.

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**Abstract**

**Ring nematode (*Mesocriconema xenoplax*) reduces prune (*Prunus domestica*) yields through root damage from direct feeding and by placing trees under stress that predisposes them to bacterial canker (*Pseudomonas syringae*). Two experiments were conducted in randomized design in prune orchard replant sites in Sutter County, California USA. The location had a history of ring nematode and bacterial canker. In the first experiment, the following treatments were applied via flood irrigation: 1) untreated control, 2) 950 liters of sodium tetrathiocarbonate (NaTet)/ha applied before planting, 3) 475 liters of NaTet/ha applied before planting followed by postplanting applications of 209 liters/ha, and 4) 950 liters of NaTet/ha applied preplanting followed by postplanting applications of 418 liters/ha. Postplanting applications were applied at 6 and 19 months. The trial was sampled for nematodes before treatments were applied and then at 3, 6, 9, 12, 15, 19, 21, 24, 28, 32, 35, 37, and 39 months after planting. Prior to the first application, there were no significant differences in nematode populations. Compared to the untreated, significant ($P \leq 0.05$) reductions in nematode populations occurred with each of the NaTet treatments. At the conclusion of the trial, trunk circumferences were greater in the treated tress than in the untreated. Survival of treated tress ranged from 88 to 100%, while 50% of untreated trees died from bacterial canker. In Trial 2, flood irrigation treatments were applied after planting: 1) untreated control, 2) 95 and 105 liters/ha applied at 0 and 12 months, respectively, and 3) 190 and 209 liters/ha applied at 0 and 12 months, respectively. Nematodes were sampled before planting and at 2, 9, 12, 14, and 18 months after planting. In this trial, there were no significant nematode reductions, and no reduction in symptoms of bacterial canker compared to untreated. Survival rates of 67% in untreated and 50% in treated trees were not statistically different, but the low survival in all treatments would be of economic concern to growers. When applied preplant by flood irrigation, NaTet shows promise for reducing ring nematode and bacterial canker.**

**Keywords:** *Mesocriconema xenoplax,* nematode, nematicide, *Prunus domestica*

## INTRODUCTION

California is the primary producer of dried prunes (*Prunus domestica*) in the United States, producing 99% of the U.S. production and 40% of the world's supply (Olson et al., 1982). About 19,000 ha are concentrated in the Sacramento and San Joaquin Valleys (California prunes, 2022).

Ring nematode (*Mesocriconema xenoplax*) reduces prune yields in California through root damage from direct feeding increasing stress which predisposes them to bacterial canker (*Pseudomonas syringae*) (English et al., 1982; Lownsbery, 1981; Mojtahedi and Lownsbery, 1975; Mojtahedi et al., 1975; Sayler and Kirkpatrick, 2003; Southwick et al., 1999). In 1974, 38% of prune orchards in California were infested with ring nematode (Lownsbery et al., 1974). It is likely that the

number of infested acres has increased because of the ease with which nematodes can be spread on farm equipment, in irrigation water, and by other means.

Symptoms of bacterial canker include blighted buds, blossoms, and leaves; and annual cankers which occur on and can result in the girdling and death of limbs or trees (English, 1981; English et al., 1980). Cytospora canker fungus frequently invades bacterial cankers and may cause further damage to the tree (English et al., 1980). Yield losses vary from an estimated low of 10% to as much as 100% for killed trees.

The severity of bacterial canker has often been reduced by use of preplant and/or postplant soil fumigation for control of nematodes (English and DeVay, 1964; English et al., 1983; English et al., 1978). For example, DBCP (dibromochloropropane) increased tree growth and reduced bacterial canker (English et al., 1980; English et al., 1978). Since the loss of this nematicide more than 20 years ago, the incidence of bacterial canker has been increasing. Two field trials were conducted to determine the effectiveness of the carbon disulfide liberator sodium tetrathiocarbonate (Desaeger et. al, 2020) to manage ring nematode and bacterial canker in prune orchards.

**MATERIALS AND METHODS**

In two field trials, sodium tetrathiocarbonate (NaTet, Enzone, ArystaLifescience, Cary, NC) that liberates carbon disulfide when diluted in water and applied to soil was applied as a drench application in individual tree basins of 18.8 to 37.2 $m^2$ an area covering 50% of the area between trees. Treatments were designed to simulate flood applications to larger areas. Prior to application, the material was diluted with water in a stainless-steel tank. The amounts of diluted material specified below for each treatment were then applied to the basins around individual trees. The trials were conducted in a randomized design in prune orchard replant sites in Sutter County, California USA in locations that had a history of ring nematode and bacterial canker. The orchards were planted to 'French prune' on Myrobalan 29C.

In both trials, soil samples were taken with a 2.5 cm diameter tube to a depth of 46 cm to monitor nematode populations. A sample consisted of 10 composite soil cores from an individual replicate. Ring nematodes were extracted from soil samples via elutriation followed by sugar centrifugation (Byrd et. al, 1966; Byrd et. al., 1976). Extracted nematodes were identified and counted at 45x magnification under a stereoscopic dissecting microscope (Bausch & Lomb, Bridgewater, NJ). Bacterial canker was evaluated visually using a rating scale developed by the authors: 0=Healthy,1=Disease present confined to trunk, 2=Scaffold dead, trunk gumming, 3=Leaves yellow, tree weak, expected to die, 4=Dead with leaves, and 5=Dead without leaves.

Data was analyzed by Analysis of Variance (ANOVA) and Repeated Measures ANOVA ($P \leq 0.05$) followed by Fisher's Protected Least Significant Difference Test (JMP, SAS Institute).

**Trial 1 - Pre and postplant drench trial**

In Trial 1, the following treatments were applied via flood irrigation 3 weeks prior to planting trees: 1) untreated control (Untreated), 2) 950 liters of NaTet/ha applied preplant only (Pre Only), 3) 475 liters of NaTet/ha applied preplant followed by postplanting applications of 209 liters/ha (Low Plus), and 4) 950 liters of NaTet/ha applied preplant followed by postplant applications of 418 liters/ha (High Plus). Postplant applications were applied at 6 and 19 months. There were 8 individual tree replicates for each treatment. The trial was sampled for nematodes before treatments were applied and at 3, 6, 9, 12, 15, 19, 21, 24, 28, 32, 35, 37, and 39 months after treatment. Preplant treatments were applied using 284 liters of water per basin and postplanting treatments in 379 liters of water per basin. Circumference of each tree trunk was measured at 60cm above the ground at 0, 12, and 24 months. Bacterial canker was rated at 24 months. Survival was recorded at 24 months.

**Trial 2 - Postplant drench trial**

In Trial 2, trees were planted 6 months prior to the first application. The following flood irrigation treatments were applied: 1) untreated control (Untreated), 2) 95 and 105 liters NaTet/ha (Low Plus) applied at 0 and 12 months, respectively, and 3) 190 and 209 liters NaTet/ha (High Plus) applied at 0 and 12 months, respectively. The first applications were applied in 151 liters of water per basin and the second applications were applied in 189 liters of water. There were 12 individual tree replicates per treatment. The trial was sampled for nematodes preplant and at 2, 9, 12, 14, and 18 months. Bacterial canker was rated at 12 and 18 months. Survival was recorded at 18 months.

**RESULTS**

**Trial 1 - Pre and postplant drench trial**

Prior to the first application (0 month), there were no significant differences between treatments in nematode populations (Table 1 across). Compared to the untreated, significant ($P \leq 0.05$) reductions in nematode populations occurred with each of the NaTet treatments. Looking at populations for untreated over the 39 months of the trial, there were no differences (Table 1 down). For Pre Only and High Plus treatments, compared to month 0, all subsequent sampling dates had reduced populations of ring nematode ($P \leq 0.05$). For Low Plus, populations were lower than month 0 on six dates (3, 6, 9, 21, 24, and 35 months) ($P \leq 0.05$). Comparisons between treatments on each sampling date show that nematode populations were lower than Untreated for all NaTet treatments at 3, 6, 9, 21 and 24 months (Table 1 across) ($P \leq 0.05$). Pre Only and High Plus were also lower at 19 months ($P \leq 0.05$).

Table 1. Effect of pre and postplant drench treatments on densities of ring nematode per 1,000 $cm^3$ soil.

| | Untreated | | | Pre Only[a] | | | Low Plus | | | High Plus | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time[b] | | dn[c] | ac | | dn | ac | | dn | ac | | dn | ac |
| 0 | 513±192[d] | a | x | 288±143 | a | x | 431±263 | a | x | 1075±448 | a | x |
| 3 | 363±182 | a | x | 0±0 | b | y | 6±6 | c | y | 0±0 | b | y |
| 6 | 438±203 | a | x | 0±0 | b | y | 13±13 | c | y | 6±6 | b | y |
| 9 | 313±111 | a | x | 0±0 | b | y | 13±13 | c | y | 6±6 | b | y |
| 12 | 269±140 | a | x | 0±0 | b | x | 231±100 | abc | x | 256±245 | b | x |
| 15 | 336±119 | a | x | 38±38 | b | y | 269±161 | abc | x | 43±22 | b | x |
| 19 | 392±189 | a | x | 6±6 | b | y | 163±82 | abc | xy | 64±45 | b | y |
| 21 | 113±27 | a | x | 6±6 | b | y | 25±13 | c | y | 29±14 | b | y |
| 24 | 275±127 | a | x | 13±13 | b | y | 56±28 | c | y | 14±13 | b | y |
| 28 | 38±17 | a | y | 31±21 | b | y | 363±148 | ab | x | 136±51 | b | xy |
| 32 | 150±48 | a | xy | 6±6 | b | y | 250±129 | abc | x | 93±64 | b | xy |
| 35 | 38±17 | a | xy | 0±0 | b | y | 106±41 | bc | x | 29±20 | b | y |
| 37 | 113±22 | a | xy | 31±31 | b | y | 213±60 | abc | x | 93±31 | b | xy |
| 39 | 163±53 | a | xy | 14±13 | b | y | 143±57 | abc | xy | 250±111 | b | x |

[a]Pre Only = a single preplant application of 950 liters/ha. Low Plus = a preplant application of 475 liters/ha followed by 209 liters/ha postplant at 6 and 19 months. High Plus = a preplant application of 950 liters/ha followed by 418 liters/ha postplant at 6 and 19 months.

[b]months after first treatment

[c]dn (down) = comparison of treatments within a column, ac (across) = comparison of all treatments on a single date.

[d]Each figure is the mean of 8 replicates ± standard error. Means followed by the same letter are not significantly different at P≤0.05.

Prior to the first application and at 12 months, there were no differences in trunk circumference for NaTet treatments compared to Untreated ($P \leq 0.05$). At 12 and 24 months, trunk circumferences for all NaTet treatments were greater than untreated ($P \leq 0.05$). At 24 months, the

bacterial canker rating was lower for Low Plus and High Plus than untreated ($P \leq 0.05$). Survival of treated tress ranged from 88%for Pre Only to 100% for Low Plus and High Plus. Fifty percent of untreated trees died from bacterial canker.

Table 2. Effect of pre and postplant drench treatments on trunk circumference (cm), severity of bacterial canker, and survival.

| | Months after first treatment | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Trunk Circumference | | | | | | Bacterial Canker[b] | | Survival (%) |
| Treatment[a] | 0 | | 12 | | 24 | | 24 | | 24 |
| Untreated | 2.74±0.03[c] | ab | 4.93±0.07 | a | 14.02±0.61 | b | 2.38±0.52 | a | 50 |
| Pre Only | 2.69±0.03 | b | 5.39±0.05 | a | 16.34±0.56 | a | 1.00±0.52 | ab | 88 |
| Low Plus | 2.92±0.03 | a | 5.13±0.05 | a | 16.59±0.53 | a | 0.13±0.52 | b | 100 |
| High Plus | 2.82±0.03 | ab | 5.28±0.05 | a | 16.76±0.53 | a | 0.00±0.52 | b | 100 |

[a]Pre Only = a single preplant application of 950 liters/ha. Low Plus = a preplant application of 475 liters/ha followed by 209 liters/ha postplant at 6 and 19 months. High Plus = a preplant application of 950 liters/ha followed by 418 liters/ha postplant at 6 and 19 months.

[b]0 = healthy, 1 = disease present, confined to trunk, 2 = scaffold dead, trunk gumming, 3 = leave yellow, tree weak, expected to die, 4 = dead with leaves, 5 = dead without leaves

[c]Each figure is the mean of 8 replicates ± standard error. Means in a column followed by the same letter are not significantly different at P≤0.05.

**Trial 2 - Postplant drench trial**

Prior to the first application (0 month), there were no significant differences between treatments in nematode populations (Table 3 across) ($P \leq 0.05$). Numerically, over the course of the trial, nematode populations increased for all treatments. In this trial, there were no significant nematode reductions among treatments (Table 3 down and across) to monitor nematode populations There were also no differences in symptoms of bacterial canker (Table 4) ($P \leq 0.05$). Numerically, at 12 and 18 months, bacterial canker was more prevalent in both Low Plus and High Plus than in Untreated. Tree survival at the end of the trial was 67% in untreated and 50% in Low Plus and High Plus.

Table 3. Effect of postplant drench treatments on densities of ring nematode per 1,000 $cm^3$ soil.

| | Untreated | | | Low Plus[a] | | | High Plus | | |
|---|---|---|---|---|---|---|---|---|---|
| Time[b] | | dn[c] | ac | | dn | ac | | dn | ac |
| 0 | 296±148[d] | a | x | 525±229 | bc | x | 579±218 | ab | x |
| 2 | 792±271 | a | x | 742±216 | abc | x | 838±377 | ab | x |
| 9 | 575±245 | a | x | 391±113 | c | x | 192±134 | b | x |
| 12 | 1375±461 | a | x | 1438±483 | a | x | 1041 461 | a | x |
| 14 | 1191±375 | a | x | 1005±282 | abc | x | 800±269 | ab | x |
| 18 | 1246±570 | a | x | 1264±420 | ab | x | 583±192 | ab | x |

[a]Low = 95 and 105 liters/ha applied at 0 and 12 months, respectively.
High = 190 and 209 liters/ha applied at 0 and 12 months, respectively.

[b]Months after first treatment.

[c]dn (down) = comparison of treatments within a column, ac (across) = comparison of all treatments on a single date.

[d]Each figure is the mean of 12 replicates ± standard error. Means followed by the same letter are not significantly different at P≤0.05.

Table 4. Effect of postplant drench treatments on severity of bacterial canker, and survival.

| Treatment[b] | Bacterial Canker Rating (months after first treatment)[a] 12 | | 18 | | Survival (%) |
|---|---|---|---|---|---|
| Untreated | 1.58±0.55[c] | a | 1.92±0.63 | a | 67 |
| Low Plus | 2.67±0.55 | a | 3.00±0.63 | a | 50 |
| High Plus | 2.50±0.55 | a | 3.00±0.63 | a | 50 |

[a]0 = healthy, 1 = disease present, confined to trunk, 2 = scaffold dead, trunk gumming, 3 = leave yellow, tree weak, expected to die, 4 = dead with leaves, 5 = dead without leaves

[b]Low = 95 and 105 liters/ha applied at 0 and 12 months, respectively.
High = 190 and 209 liters/ha applied at 0 and 12 months, respectively.

[c]Each figure is the mean of 12 replicates ± standard error. Means followed by the same letter are not significantly different at P≤0.05.

## DISCUSSION AND CONCLUSIONS

When applied preplant by flood irrigation, NaTet shows promise for reducing ring nematode and bacterial canker. Natural fluctuations in ring nematode populations make differences due to treatments harder to elucidate. These fluctuations have been reported in previous population studies of this nematode in California (Westerdahl et. al, 2013). They are of significance to growers with respect to: 1) the timing of sampling to detect nematodes, 2) the timing of chemical applications for nematode control (or perhaps other management techniques), and 3) the timing of sampling to evaluate the effectiveness of a management practice.

Ring nematode has not been shown to transmit bacterial canker to prune trees. Rather the relationship is one of stress predisposing trees to bacterial canker. In a study on fertilization of prune trees, Southwick et al. (1999) reported an increased incidence of bacterial canker when no nitrogen was applied. Additional predisposing factors include low pH, sandy texture, or a shallow hardpan (Sayler and Kirkpatrick, 2003). Our trials were conducted in an area called a "bacterial canker hole" by local growers. This is an area where trees have been planted and died a number of times. Therefore, significant reductions in bacterial canker ($P \leq 0.05$) combined with the numerical increase in tree survival in treated plots is of economical significance to growers.

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