ETIOLOGY AND CONTROL OF LETHAL CANKER SYNDROME CAUSED BY *PHYTOPHTHORA* SPP. ON ALMOND

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Background

Phytophthora species are important soilborne pathogens of many crops, including almond trees. Depending on the species and the environmental conditions, *Phytophthora* can infect most almond tree parts, including the roots, root crown, trunk, scaffold crotch, and scaffold branches. Risk of root or crown infection by *Phytophthora* species is greatest during cool to moderate temperatures with prolonged or frequent water saturation in or on soil. The water-filled pores in a saturated soil favor reproduction of the pathogen and dispersal of its swimming zoospores, which are the principal agents of root system infection. In cool wet weather, pruning wounds are subject to infection by *P. syringae*, resulting in "pruning wound canker". This disease usually is not serious on almond trees that are more than a few years old because *P. syringae* is sensitive to high temperatures, and the cankers cease development in late spring and summer. This project is focused on biology and control of another disease, "lethal Phytophthora canker" (LPC), caused by *P. cactorum* and *P. citricola*. Unlike the pruning wound canker, LPC kills mature almond trees by girdling the scaffolds and/or trunk. The lethal characteristic of LPC results from rapid tree colonization by the pathogens and the perennial potential of the cankers.

Objectives:

1. Determine occurrence of lethal Phytophthora canker (LPC) in selected Northern, Central, and Southern Central Valley almond orchards.

2. Monitor parts of almond trees on which LPC infections occur.

3. Determine seasonal effects on LPC development.

4. Develop appropriate control measures for LPC.

Objectives 1 and 2.

Determining occurrence of LPC and monitoring parts of almond trees affected. To date this year, we have focused on work in Kern County. Previous formal field surveys indicated that *P. cactorum* and *P. citricola* are both causing LPC there (Almond Board reports for 1997-99). Surveys in the affected orchards frequently associated *P. cactorum* with infections of the root crown and trunk and less frequently associated it with trunk, scaffold crotch and scaffold branch cankers. In contrast, *P. citricola* was infrequently associated with soilborne infections of the trunk and root crown and commonly associated with the above-ground infections. LPC has occurred in flood- as well as microjet-irrigated orchards in Kern County.

Objective 3.

Determining seasonal effects on LPC development. To determine the times of the year that LPC cankers are active and when they grow most rapidly, making post-infection control measures most critical, we conducted monthly inoculations with *P. cactorum* and *P. citricola* in a commercial almond orchard in Kern County. Each month since October 1999, a separate set of eight trees was inoculated on two scaffold branches per tree; four trees received *P. cactorum* and four received *P. citricola*. The inocula were introduced under 1 cm^2 bark patches and consisted of 1-cm^2 mycelial agar culture squares. Control branches were "inoculated" identically, except with sterile agar. Canker length and width was measured 3 weeks after inoculation, then the inoculated branches were cut off to prevent invasion of the remainder of the tree.

Significant cankers developed within 3 weeks following all inoculations except those in early December 1999, when only small amounts of tissue death were evident around inoculation points (Figure 1). Average air temperature in the orchard tree canopy was 41 F in December. It increased to 49 F in January and February, followed by 56, 60, 69, 75, and 76 F in March, April, May, June and July, respectively. The combination of cool temperature and tree dormancy in December apparently slowed canker development markedly. The pathogens caused more disease within the 3-week periods as temperatures warmed in the spring and summer (Figure 1). Both *P. cactorum* and *P. citricola* caused large cankers during summer months, despite maximum temperatures that often exceeded 95 F.

LPC infections are probably most likely when free moisture occurs for prolonged periods on the tree surfaces. Once cankers are initiated, however, our results suggest that they can expand throughout most of the year. Therefore, if effective therapeutic canker treatments can be registered, it will be best to apply them as soon as LPC cankers are discovered, whether in winter, spring, summer, or fall. The monthly inoculations are continuing so that repeatability of the results can be determined.

Objective 4.

Developing appropriate control measures for LPC.

Preventative treatments. Foliar sprays with the fertilizer Nutri-Phite P+K (0-28-26 formulation) were tested for their ability to suppress subsequent development of LPC cankers in three experiments. In each test, the material was applied by an air-blast sprayer at 4 pints/acre in 175-185 gallons of water, and complete above-ground tree coverage was achieved. Depending upon the experiment, controls were left untreated or were sprayed with water at 175-185 gal/acre. In the first test, a spray with Bordeaux mixture (10-10-100, 3.1 gallons hand-sprayed on lower half of each tree) was used as a comparison treatment. Two to 3 weeks after spray application, the trees were inoculated with *P. citricola* or *P. cactorum*. In the first experiment, the inoculations were made either in wounded bark or on non-wounded bark or latent buds. In the second two experiments, only bark-wound inoculations were used.

Only wound inoculations resulted in cankers. Fall application of Bordeaux mixture did not suppress cankers from the bark-wound inoculations (Figure 2). This was expected, because the copper does not have significant systemic activity. The Nutri-Phite spray on 10/29/99 effectively protected trees from wound inoculation with *P. citricola* on 11/7/99 (Figure 2 A, B) and provided strong canker suppression following the inoculations on 2/08/00 (Figure 2 C, D). The protection afforded by the fall Nutri-Phite spray had lasting consequences; the treated trees inoculated with *P. citricola* were still healthy on 8/9/00 (Figure 3). Late dormant (2/08/00) application of Nutri-Phite was ineffective (Figure 4 A), probably because there were no leaves to facilitate uptake of the material. On the other hand, spray application of Nutri-Phite on 3/31/00 provided strong protection from inoculations with *P. citricola* on 4/15, 5/17, and 6/19 and moderate protection from inoculations with *P. cactorum* on the same dates (Figure 4 B). The results indicate that foliar spray applications of the Nutri-Phite fertilizer formulation, if properly timed, offer a very important side benefit of protection from lethal Phytophthora cankers. The effect for *P. citricola* may be stronger than that for *P. cactorum*.

Therapeutic treatments. Topical chemical treatments were tested for therapeutic control of LPC cankers on commercial almond trees by establishing cankers caused by *P. citricola*, measuring the cankers, applying the test materials on the cankers, and measuring post-treatment canker expansion. The inoculations with *P. citricola* were completed on 10/22 by placing mycelial agar disks under bark patches on scaffold branches and tree trunks. On 12/2, canker incidence and size were determined and treatments of Aliette WDG (1 lb. per gal. water), Ridomil Gold (1 qt. per 3 gal. water), or modified "magic elixir" (500 ml boiled linseed oil, 180 g basic $CuSO_4$, 80 ml Hexol) were applied with paint

brushes to cover the canker-affected bark and extend at least 10-20 cm beyond the margins of diseased tissue. A control for the topical treatments received no chemical. Just before the chemical treatments, a hatchet was used to make cuts through the bark and into the wood on half the number of branch and trunk sites to receive each chemical or control treatment. The cuts were about 5 cm wide and oriented in a "fish-scale" manner to facilitate chemical retention and penetration. About 5-15 cuts were made per inoculation/canker site, depending on canker size. The other branches received no bark preparation before topical treatments were applied.

The topical treatments with Aliette or Ridomil significantly suppressed subsequent expansion of cankers caused by *P. citricola*, but the elixir did not (Fig. 5 A, B). The bark cuts made with a hatchet before treatment application did not significantly improve efficacy. It is possible that shaving of the bark at canker margins during canker measurement improved chemical penetration into the bark. The results indicate that topical concentrated applications of Aliette and Ridomil both hold promise for therapeutic treatment of LPC cankers, although Aliette was more effective overall. These treatments are not currently registered for use on almond.

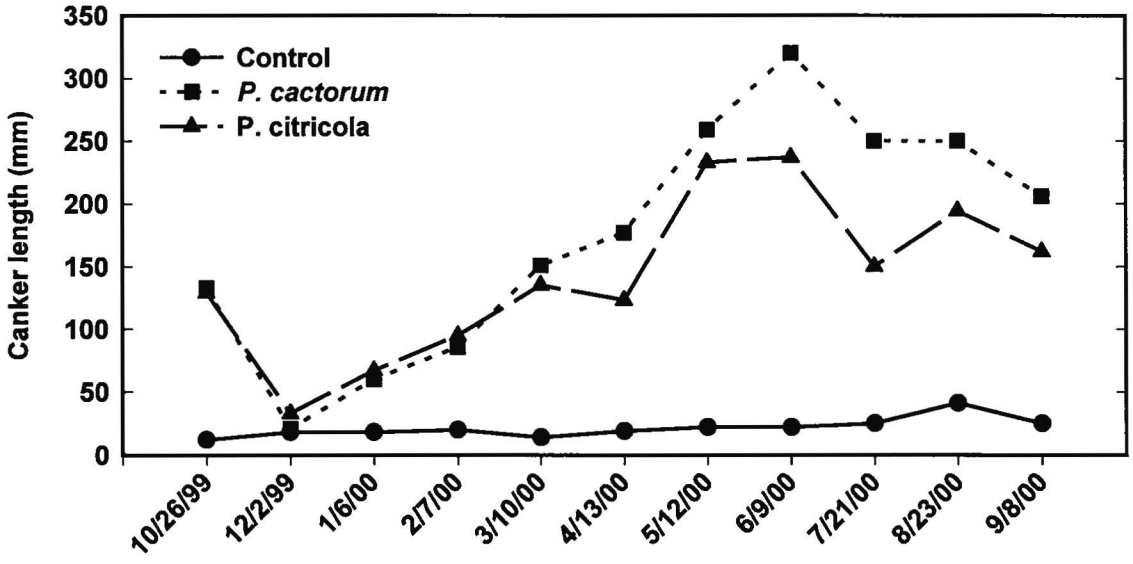

Figure 1. Seasonal effects on development of lethal Phytophthora cankers in a commercial almond orchard. Each month, a separate set of eight Nonpareil almond trees was inoculated on scaffold branches, four trees *with P. cactorum* and four with *P. citricola*. At each inoculation point (two scaffolds per tree), a 1-cm^2 patch of agar culture covered with *Phytophthora* was inserted under a bark patch of the same size. Control branches received sterile agar. Canker length and width were measured 3 weeks after inoculation. Note extensive canker development throughout most of the year.

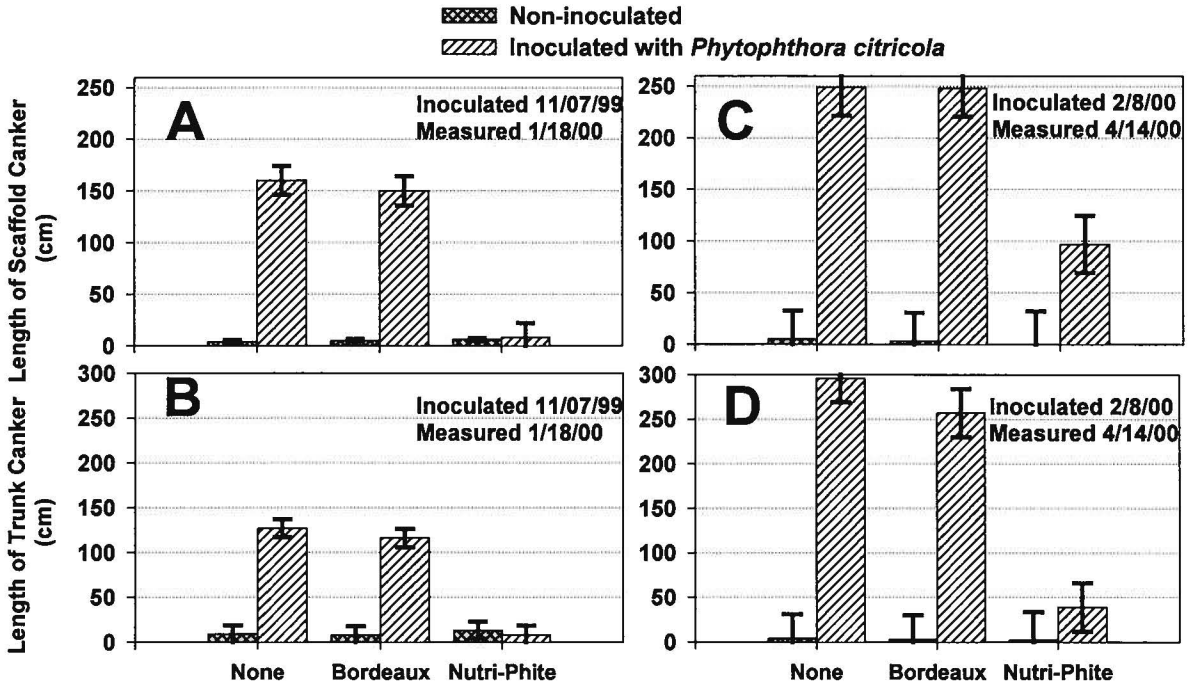

Figure 2. Effect of pre-inoculation spray treatments on subsequent development of lethal Phytophthora cankers caused by *P. citricola* on commercial almond trees. Bordeaux mixture (10-10-100, 3.1 gal/tree, applied on lower half of trees), Nutri-Phite P+K (0-28-26 formulation; 4 pints per sprayed A in 175 gal water; complete foliage spray), and a non-sprayed control were applied on 10/29/99. On 11/17/99 and 2/8/00, four replicate trees were wound inoculated with *P. citricola* and four with sterile agar (control). Resulting cankers were measured 2 months after inoculation. Error bars delimit 95% confidence intervals. Note that Nutri-Phite prevented development of cankers following inoculation on 11/7 (**A** and **B**) and strongly suppressed canker development following inoculation on 2/8 (**C** and **D**).

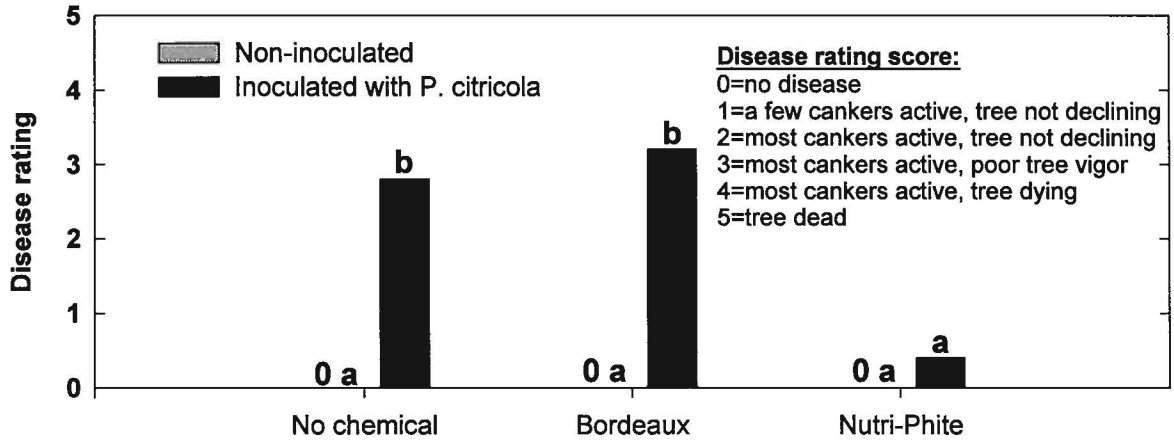

Figure 3. Effect of pre-inoculation spray treatments on survival of commercial almond trees inoculated with *Phytophthora citricola.* Trees sprayed on 10/29/99 and inoculated on 11/17/99 or 2/8/00 as described above (Fig. 2) were rated on 8/9/00 for severity of disease caused by the pathogen. Means without letters in common are significantly different (95 % confidence intervals). Note that the canker protection provided by Nutri-Phite persisted.

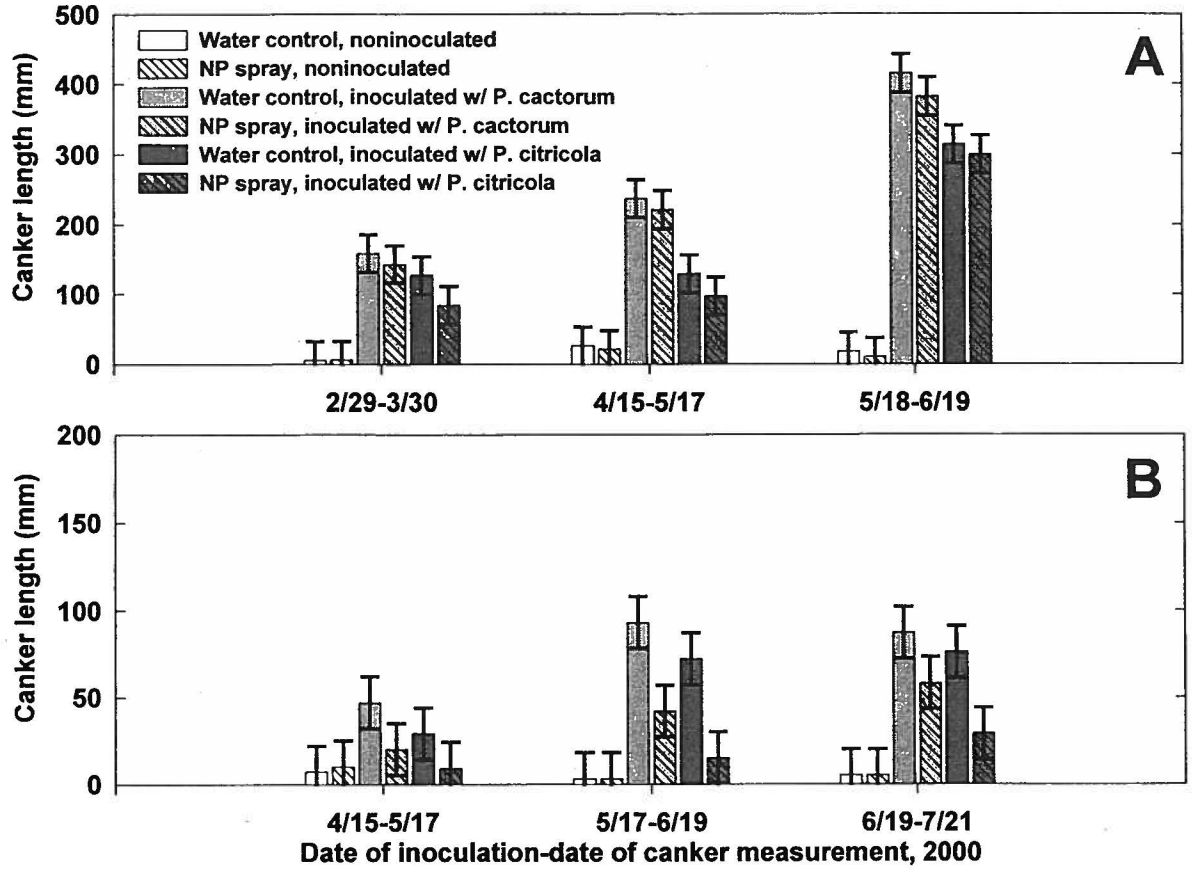

Figure 4. Effect of Nutri-Phite P+K spray treatment (0-28-26 formulation; 4 pints/acre in 175-185 gal water, complete foliage spray) applied **A**, 2/8/00 or **B**, 3/31/00 on subsequent development of lethal Phytophthora cankers on commercial almond trees. On 2/8, trees were emerging from dormancy but leaves and blooms were absent. On 3/31, leaves had expanded and shoot growth was well underway. X axis labels indicate dates of inoculation and canker measurement. The canker lengths are combined means from trunk and scaffold canker measurements, and error bars delimit 95% confidence intervals. Note that dormant application of Nutri-Phite (**A**) prevented neither *P. cactorum* nor *P. citricola* cankers. The application after dormancy (**B**) suppressed both types of canker, but it was more effective for *P. citricola* than for *P. cactorum*.

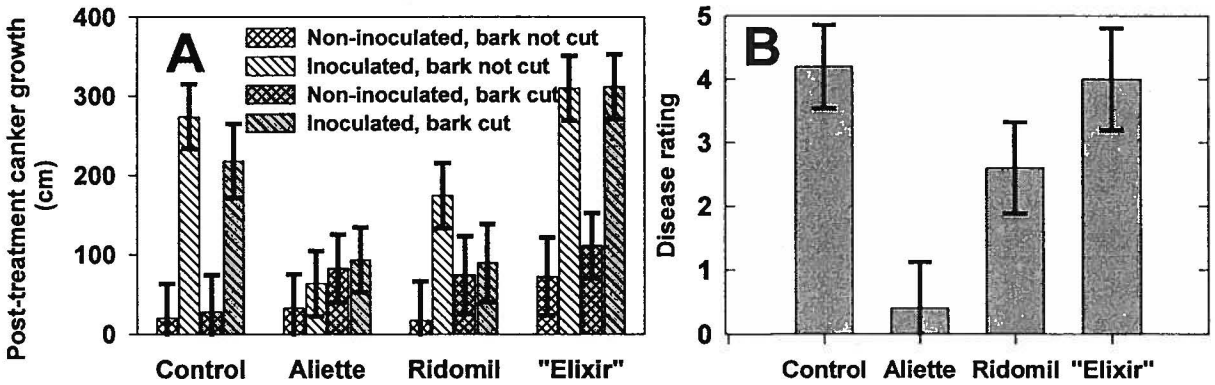

Figure 5. Effects of therapeutic topical treatments on growth of existing *P. citricola* cankers on commercial almond trees. **A**, expansion of the cankers during 4 months after treatments; **B**, health of inoculated trees 8 months after treatments (disease rating scores: 0= no disease, 5= tree dead, as in Fig. 3). Scaffold branches and trunks of the trees were wound inoculated with *P. citricola*-colonized agar or sterile agar (control) on 10/22/99. On 12/2, canker incidence and size were determined, and the canker treatments were applied (see text). Just before the chemical treatments, a hatchet was used to make cuts through the bark and into the wood on half the number of branch and trunk sites to receive each chemical or control treatment. The cuts were angled upwards to facilitate chemical retention and penetration. Error bars delimit 95% confidence intervals. Note that the most effective treatment, overall, was Aliette. "Elixir" had no effect. There was no major benefit from bark preparation.