Biological control of CALIFORNIA OAKMOTH *with Bacillus thuringiensis*

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STUDIES WERE BEGUN early in 1969 on the microbial ecology of the California oakmoth *Phryganidia californica*. During the early summer the controversy over the possible withdrawal of DDT became widely publicized, and landowners and city dwellers made many inquiries about the environmental and public health aspects of the routine spraying of oak trees for oakmoth control. By this time, the studies initiated earlier had provided sufficient information to indicate that *Bacillus thuringiensis* would probably be highly effective for oakmoth control. If so, it would provide a valuable alternative to the Sevin or, more commonly, DDT — lead arsenate mixtures currently in widespread use. Accordingly, a series of field trials was organized with the cooperation of the California State Division of Highways, and the East Bay Regional Park District to draw up, if possible, a recommendation for the detection of incipient oakmoth infestations and their economic control with *Bacillus thuringiensis*. Three areas of differing climate—in Monterey, San Benito and Alameda counties—all with severe oakmoth infestation were chosen for the trials. In all areas the host trees were coast live oaks, *Quercus agrifolia*.

Sampling technique

Trees at each field trial location were coded individually so that numbers of larvae could be followed on a tree-by-tree basis. Twenty-five shoots on each tree were inspected at random and the number of oakmoth eggs and larvae noted. On average, each shoot contained between 10 and 11 leaves; thus over two hundred and fifty leaves per tree were sampled. Earlier work had shown that this sampling procedure provided a workable indication of the numbers of larvae present (and thus of the damage to be expected) and also kept the required man-hours to a practical level. A drawback to the method is that only shoots from ground level to approximately 7 ft are sampled. The count is therefore biased low, since in most cases the moths lay their eggs well up in the canopy of the tree.

At Monterey a personnel hoist was available on one occasion and it was possible to compare counts of larvae made from the ground with those made in the upper canopy at a height of between 25 and 30 ft. Counts recorded in the upper canopy were approximately three times the number of larvae counted from ground level. This factor will be taken into account when forecasting probable damage to infested trees based on counts of larvae made only from the ground. During all counts, the numbers of other insects were also recorded, especially the two major oakmoth predators, *Chrysopa* species, mainly *Chrysopa carnea* (Neuroptera, Chrysopidae) and *Podisus maculliventris* (Hemiptera, Pentatomidae).

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BACILLUS THURINGIENSIS preparations proved to be highly effective for oakmoth control during field trials conducted in three areas of differing climate in northern California. The Bacillus thuringiensis preparations tested were Biotrol Dustable BTB 183 2.5D, Biotrol Wettable BTB 183 25 W, and Thuricide 90 TS 950-T. They were found to be equally effective for oakmoth control, though they differed in persistence of viable spores. Three types of equipment were used to apply the sprayable preparations, and all produced effective coverage but showed marked differences in wastage of material. Only one type of equipment was available for applying the dustable preparation. Application was timed to coincide with the early third instar of the oakmoth larvae, when a change in feeding behavior increased their exposure to the Bacillus thuringiensis. All three preparations were apparently fully compatible with the equipment for application, and no handling or disposal difficulties were encountered. The numbers of insect predators of oakmoth larvae were apparently unchanged by the Bacillus thuringiensis treatments and no phytotoxicity was noticed.

Timing

During the first and second instars, oakmoth larvae feed by skeletonizing the leaves, usually from the lower surface, leaving the upper surface of the leaf intact. They are therefore protected from *Bacillus thuringiensis* sprays which, with most equipment, are applied largely to the upper leaf surfaces. After the second moult, the young larvae, now third instar, are able to bite through the leaf, consuming its entire thickness. Their exposure to *Bacillus thuringiensis* sprays is then very greatly increased, since they consume the upper surface and feed from the edge of the leaf where the *Bacillus thuringiensis* tends to be concentrated as the spray dries. Thus the *Bacillus thuringiensis* sprays are likely to be most effective when applied during the early third instar of the larvae. At this stage the damage caused by the larvae is insignificant. Applications made at a later stage will also be effective, but the damage sustained by the infested trees will be proportionately greater.

All applications were made during the early third instar of the larvae, except Trials B and D at San Benito, which were made during the early fourth instar.

Drift

Control trees were selected for minimal possible drift, and in most trials these trees were well to windward of the treated ones. During each application, care was taken to avoid drift to other trees previously treated, or to be treated later with a different preparation.

Monterey County

A grove of mature oak trees approximately one mile long along California State Highway 68, two miles east of Monterey was the site of one test. During the period of the trials the climate at this location was generally cool, with frequent sea mists. The average maximum shade temperature for the four days following the *Bacillus thuringiensis* application was 69°F (20.6°C). No sunshine records are available for this or the other field trial locations.

In trial A in Monterey County, the trees were sprayed with a 0.5% (i.e. 1 gal. Thuricide in 200 gals. water) suspension of Thuricide 90TS 950-T. The three easternmost trees, and the three westernmost trees in the area were left as untreated controls. The remaining trees in the mile-long grove were sprayed, and pre- and post-treatment larval counts were made of eight trees located at intervals in the grove. The application was made with a conventional trailer-mounted sprayer, equipped with a high-pressure pump and a mechanically agitated, 500-gallon tank. A single spray gun fitted with a No. 6 variable nozzle was used, with a line pressure regulated to 375 pounds per square inch.

When approximately half the trees had been sprayed, Plyac and Triton B 1956 were added to the Thuricide suspension in the tank to give a concentration of 0.005% and 0.0005% respectively to complete spraying of the area. Each sprayed tree received a thorough coverage of the Thuricide suspension, while keeping run-off to a minimum. The quantity applied to any particular tree thus depended on the density and volume of the canopy. No accurate metering device was available, but the volume of suspension used averaged 9 gallons per tree.

In trial B, an application was made by the California State Division of Highways of a 1967 preparation of Thuricide, used at the rate of 1 gallon Thuricide in 200 gallons of water. The volume applied per tree is not known. Even this very old preparation of *Bacillus thuringiensis* gave good control of oakmoth larvae.

San Benito County

The second test location was an area of approximately one-half square mile adjoining U. S. Route 101, approximately ½ mile northwest of Pinecate Peak in San Benito County. The predominantly young oak trees were on steep rocky terrain. The climate during the period of the trials was hot and dry, the average maximum shade temperature for the four days following the application was 98°F (36.7C). The rugged terrain in this area made the use of conventional wheeled equipment impractical; all applications were therefore made with knapsack equipment.

In trial A, six trees were treated with Biotrol Dustable Powder BTB 183 2.5D. Application was made by means of a motorized knapsack duster at the rate of 1½ lbs per tree. trial B included a single tree treated with 2 oz. Biotrol Wettable BTB 183 25 W in 4 gallons of water. Application was made with a Beam Oakes knapsack sprayer. Trials C and D included application of a suspension of Thuricide 90 TS 950-T to a single tree, using the Beam Oakes knapsack sprayer. For both trials the volume per tree used was 4 gallons. In Trial C the concentration of the Thuricide was 0.5% (1 in 200) and in Trial D, 0.2% (1 in 500).

Alameda County

A well defined grove of young and mature trees along the East Ridge Trail in the Redwood Regional Park, Alameda County, was the third site. The climate was typical of the east San Francisco Bay area—dry with moderate temperatures. The average maximum shade temperature for the four days following the application was 75°F (23.9°C). Redwood Regional Park is administered by the East Bay Regional Park District.

Trial A included Thuricide 90 TS, applied to eight trees as a 1 in 200 dilution with water, using an International 1944 Street Pumper type fire engine fitted with a high pressure centrifugal pump and a 1000-gallon tank. Agitation of the tank contents was maintained by

a recirculation cycle controlled with a bypass valve. Line pressure varied from 150 to 300 lbs per square inch. Delivery was made via a ¼-inch plain nozzle. With this equipment, effective coverage could only be achieved by drenching. Consequently, the volume of suspension applied per tree was high—an average of eighteen gallons, and a considerable proportion of this was wasted in run-off. In trial B, two mature trees were each treated with 3 lbs of Biotrol Dustable BBTB 183 2.5D. Application was made with a motorized knapsack duster.

Results

With an adequate concentration of viable spores of *Bacillus thuringiensis*, all larvae were killed on treated trees within two weeks. With more dilute or older preparations, the larvae were killed more slowly, an effect also to be expected when a lower dose is applied. In all trials, all treated trees sustained little or no defoliation by the fifth week after treatment, and appeared normal to the casual observer. The untreated trees at San Benito and Redwood Regional Park were by this time completely defoliated, while those at Monterey had sustained over 80 per cent defoliation.

The major predators of oakmoth larvae were found to be *Chrysopa* species, mainly *Chrysopa carnea*, and *Podisus maculiventris*. The frequency with which predators were found during sampling did not diminish after the *Bacillus thuringiensis* treatment—in contrast to trees treated with DDT-lead arsenate mixtures, where it is often impossible to detect these predators for some weeks after treatment.

Persistence

Viable spores of Biotrol Wettable BTB 183 25 W could not be detected on treated foliage in the field one week after application. The very intense sunlight and high temperatures (98°F.) during the period of the trials undoubtedly contributed to the extinction of the spores. Nevertheless the preparation gave good control of oakmoth larvae.

Both Biotrol Dustable BTB 183 25 D and Thuricide 90 TS persisted up to three weeks on treated foliage although with a steadily reducing viable spore count. Both preparations produced a rapid, thorough kill of oakmoth larvae. The addition of Plyac and Triton B 1956 did not appreciably enhance the persistence of viable spores of Thuricide, nor the rate of kill of larvae.

Long-term effects

Certain insect pathogens will multiply within their hosts and persist long enough in the environment to exert a suppressive effect on the insect population over several generations. *Bacillus thuringiensis* is not such a pathogen, but must be reapplied when insect numbers become sufficiently high to cause economically important damage if left uncontrolled.

The use of *Bacillus thuringiensis* is not restricted by a residue tolerance requirement, nor is there any cutoff date for a wide variety of registered agricultural crops and forest trees. Massive doses of *Bacillus thuringiensis* have proved to be non-toxic for man and other vertebrates, and have caused no adverse effects on behavior or reproduction. Bees and most beneficial insects are unaffected by *Bacillus thuringiensis* at doses they would encounter in the field. Toxicology studies were commenced in 1951 and the first temporary exemption of tolerance requirements for application to food and forage crops was granted by the Food and Drug Administration in 1958. A full exemption was granted by the F.D.A. in 1960, and by the Canada Department of Agriculture in 1961.

Detection of infestations

In Northern California there are two generations of oakmoth each year; oak trees should be inspected for oakmoth larvae during mid-March and late July, before any oakmoth damage is evident. At these times of year oakmoth larvae will be about ¼ inch long, with large heads and greenish bodies with black speckles. They are more likely to be found on the underside of the leaves, often in groups, where they feed by skeletonizing the leaf surface. If 25 shoots are inspected at random, with the operator moving round the tree, and the total number of larvae found is greater than fifteen, then it is probable that the tree will be severely damaged during the following two months. A count of 10 indicates moderate damage to be expected, while a count of five or less suggests that the tree will not sustain noticeable damage during the following season, and will not require treatment for oakmoth. If only a few shoots can be checked, then these should be on the leeward or sheltered side of the tree, since the moths generally favor sheltered positions to alight and lay their eggs. Larvae counts mentioned offer only a rough guide based on amounts found adequate for landscaped areas with many oak trees. Where only a few "specimen" trees are involved, a more thorough check would be advisable.

Control recommendations

Should the number of larvae indicate that some control measure will be necessary, arrangements should be made to treat the infested trees with one of the *Bacillus thuringiensis* preparations listed below. To be most effective, the treatment should be made when the larvae begin to feed at the edges of the leaves. If the trees were checked at the times indicated, the larvae will reach this stage after two to three weeks. When the larvae are first seen to feed at the leaf edges, a thorough application of the *Bacillus thuringiensis* preparation should be made. It is important to realize that with all *Bacillus thuringiensis* preparations, thorough coverage is essential for good control.

The *Bacillus thuringiensis* preparations found to be effective for oakmoth control are (alphabetical order): Biotrol Dustable BTB 183 2.5 D, Biotrol Wettable BTB 183 25 W (at the rate of ½ oz per gallon of water), and Thuricide 90 TS at the rate of one part Thuricide to two hundred parts of water.

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