Metaphycus zebratus, a parasite of black scale imported from Spain in 1985, has been established in California olive orchards, where it shows promise as a biological control agent.

Biological control of black scale in olives

Kent M. Daane ❑ Leopoldo E. Caltagirone

Cultural practices that improve biological control of black scale in olive orchards are more common in northern than southern California orchards. A parasite of black scale, recently imported from Spain, has become established in northern orchards and may in time aid in black scale control.

Black scale has been a pest of olives and citrus in California since the 1880s. Aided by a high reproductive capacity and wide host range, including such common plants as oleander, peppertree, and coyote bush, the scale has spread throughout the state, causing repeated infestations and economic damage to olive and citrus orchards.

Efforts to control this scale, *Saissetia oleae*, included one of the largest biological control campaigns ever undertaken. Beginning in the 1890s, over 40 parasites were imported from Africa, Asia, Europe, Central and South America, and the Middle East. Many became established, providing some regulation, but none gave economic control in the San Joaquin Valley. These efforts were interrupted in the 1940s by the new and more damaging olive scale, *Parlatoria oleae*. Pesticides used to control olive scale (first DDT and later parathion) also suppressed black scale and superseded regulation by natural enemies. Successful biological control of olive scale made insecticide use unnecessary and black scale, without chemical suppression and few natural enemies, again rose to prominence.

In the Central Valley, black scale is a sporadic and explosive olive pest with wide fluctuations between years, regions, and orchards. Natural regulation is better in northern orchards (Sacramento Valley), while San Joaquin Valley orchards have more frequent and damaging scale outbreaks. These fluctuations are influenced by cultural practices such as pruning, but the ideal combination of practices to minimize black scale damage and maximize natural enemy effectiveness hasn't been found.

We have been investigating black scale population dynamics and the effectiveness of cultural and biological controls since 1984. Our goal is to develop an integrated pest management program for olives. As part of that effort, a black scale parasite, *Metaphycus zebratus*, was imported from Spain in 1985 and has been mass-cultured and colonized in Sacramento and San Joaquin Valley orchards. We report here on the influence cultural practices have on black scale development patterns and the resultant effect on parasite establishment. We also discuss the progress and potential of *M. zebratus*.

Procedure

Pruning, irrigation, and ground cover affect temperature and humidity in the olive tree canopy. These, in turn, markedly influence scale development and survival. To study these relationships, we selected orchards in Tehama, Madera, and Tulare counties with different cultural practices, levels of scale infestations, and natural enemy activity.

Samples from 25 trees per orchard were taken every 4 to 6 weeks. Tree, section of tree, weight, number of leaves and olives, honeydew and sooty mold coverage, other insect pests and diseases, and black scale numbers, development stage, and condition (alive, dead, or parasitized) were recorded for each sample. Scales were also collected in groups (100 to 1,000) and counted, recorded for stage and condition, and saved for parasite emergence.

Black scale biology

The large (4-5 mm), black adult scale is easily recognized in the gray and green olive tree. One scale can produce over 1,500 eggs (all of which are female) resulting in the characteristic explosive outbreak. Eggs are stored and incubated under the adult.

After hatching, the crawlers move to feed on the leaves. The crawlers are spread by wind or carried by other means, such as field workers. The first and second crawler stages (instars) are pale yellow and about 0.5 to 1.5 mm long. The second instars typically migrate from the leaves back to the branches.

The third instar is darker, with a clearly visible "H" ridge. Most growth occurs from the third to the pre-reproductive adult stage. These ashy gray stages blend with the similarly colored olive branches, making detection difficult.

An infestation becomes obvious, however, as increased feeding accompanies scale growth, and honeydew (the scale's excretion) covers the leaves. Sooty mold fungi grow on the honeydew, causing most of the economic damage by reducing photosynthesis and causing leaf loss. This condition can lower yield for 2 to 3 years.

Development patterns

In the San Joaquin Valley, trees are usually pruned low to the ground. There is little or no ground cover, and low-volume or furrow irrigation systems are common. Eggs begin hatching in May, and the summer heat kills most crawlers. Survivors develop slowly, usually remaining as first instars during the summer. Scale development quickens in the fall, and crawlers move from the leaves to the more protected branches. The scales reach the second and third instars and remain on the branches, with little activity, during the winter. Warmer spring weather brings a second period of rapid growth, and by May the scales reach the adult stage.

Most honeydew is produced during this second growth period. However, pesticides are usually applied in July and August against the first and second instars, which are more susceptible to insecticides but produce little honeydew. Economic damage may have occurred by this time, and

The management practices followed by growers in Tulare County (left)—open trees, low-volume sprinklers, and no ground cover—cause fluctuations in black scale populations and do not favor establishment of parasites. In Tehama County, olive trees are pruned high above the ground with branches of different trees touching. Combined with ground cover and high-volume sprinkler systems, this produces a favorable environment for black scale and establishment of parasites.

the sooty mold produced remains on the tree long after the pest is removed.

In the Sacramento Valley, trees are often pruned high off the ground with branches from different trees touching, closing the canopy above. This practice, particularly when combined with ground cover and high-volume sprinkler systems, produces lower temperatures and higher humidities under the canopy than above it. Summer temperatures are buffered, and the crawlers that hatch in May continue to develop with lower summer mortality than in the San Joaquin Valley.

By late summer, second and third instars are common. Development continues in the fall and, although reduced, some growth occurs during the winter. Most adults form in the spring and the explosive egg hatch is, as in the San Joaquin Valley, in May. However, a few adults are found in the fall, when an off-brooded population forms.

Comparison of typical development patterns shows a uniform progression in Tulare County (San Joaquin Valley). Orchards in Tehama County (Sacramento Valley) have an overlap of four and even five stages.

Parasite establishment

Black scale parasites are usually specific to one or two consecutive scale stages. Since the parasites are shorter-lived than the scale, they need susceptible host stages available throughout the year. In Tulare County orchards with closed canopies, scale development was synchronized, producing gaps in host availability and preventing parasite establishment.

Without parasite regulation, climate governed scale fluctuations. Keeping the canopy open maximizes summer mortality but control can be incomplete, especially during years with cool temperatures. There is little spring or winter mortality. When the canopy becomes dense, pest numbers can increase dramatically, requiring pesticide treatment and preharvest pruning (fig. 1).

In contrast, climatic conditions and parasite activity provided excellent natural control in the Tehama County orchards studied. While most of the scales followed a development pattern similar to those in Tulare County, some were ahead or behind in development and available to support a diverse group of parasites. Summer mortality was lower, because the scales had some protection beneath the canopy, but natural enemies reduced scale numbers in the fall and spring. This combination produced regular fluctuations with low pest numbers during the spring when adults are common and most honeydew is produced (fig. 2).

Parasite populations were reduced in the hot summer of 1984 when climatic conditions caused most black scale mortality. Activity was lower in 1985 while parasite populations recovered but increased quickly in 1986 when, because of mild temperatures, climatic conditions alone could not have provided control.

New natural enemy

Our findings on black scale development and parasite establishment show that, to be effective in the San Joaquin Valley, a parasite must have a tolerance to hot summers and cool winters, a wide range of susceptible host stages, and a high reproductive ability to utilize the fall and spring periods when parasite activity is favored.

Initial laboratory and field studies with *Metaphycus zebratus* have been promising. This parasite was reared from black scale on olives in southern Spain, a region with a climate like California's. In the laboratory the parasite attacks a wide range of host stages, from the third to early adult. Up to seven parasites have been found in a single host, a characteristic that could increase its efficiency at low host densities.

Field releases began in the winter of 1985 in Tehama, Glenn, and Tulare counties. Recoveries were first made in northern orchards the following spring. Mortality caused by *M. zebratus* was low compared with that by resident parasites (3.3%; n=641). Before releases resumed in the fall of 1986, however, recoveries were made in

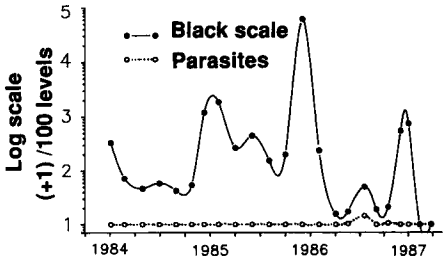

Fig. 1. Tulare County orchard with a closed canopy had an increasing scale population until a pesticide treatment and pruning in August 1986 lowered scale numbers.

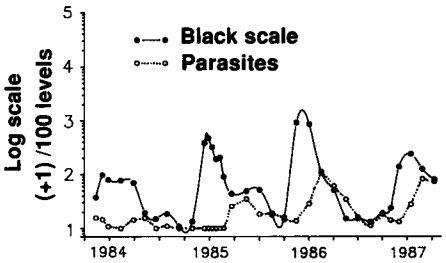

Fig. 2. Tehama County orchards had regular fluctuations with low scale numbers during the spring when most honeydew is produced. Parasite activity was high in the fall and spring and during years with cool temperatures.

all counties, indicating the parasite had survived the summer, when suitable host stages were rare.

In the second season, with improved rearing techniques, 22,000 parasites were produced and released in Fresno (1,500), Madera (3,050), Tehama (8,200), and Tulare (9,250) counties. Recoveries increased, especially in northern release orchards where *M. zebratus* was often as numerous as *Metaphycus bartletti* and *Scutellista cyanea*, the two most common parasites of the later host stages. Recovery in Tulare County has not been as promising. Release orchards had large black scale populations; recovery is thus difficult until parasite numbers increase in the field. Also, many release sites were chemically treated when scale numbers threatened production.

Conclusions

Parasite establishment in the southern San Joaquin Valley is impeded by black scale's development pattern. A combination of weather patterns and cultural methods cause the population to develop uniformly with little overlap of stages. Parasites are specific to one or two host stages; when these are not available, the parasites cannot become established in the orchard. Uniform development may also increase economic damage, because most scale growth and honeydew production occur in the spring, when conditions favor sooty mold growth.

While climate-related mortality depends on summer temperatures, cultural practices can create a shelter within the canopy even during very hot years. Until natural enemies are established, the most dependable control strategy would seem to be frequent pruning to increase heat-caused mortality.

Sacramento Valley orchards have a good combination of biological and cultural controls. Black scale becomes troublesome only when the canopy becomes too dense and a mild summer allows the pest to increase faster than the natural enemies.

Metaphycus zebratus has become established in northern orchards, confirming that this area is more favorable to biological control. We will follow the effect of this parasite on scale incidence and the competitive interactions with resident natural enemies. While recoveries in Tulare County have not been as promising, the parasite has been recovered and time is needed to determine its effectiveness.

In both northern and central regions, monitoring of scale populations is recommended to help in timing cultural or chemical control measures. A sampling program with control action thresholds is being developed for olive growers. We are also studying methods to increase biological controls through manipulation of cultural methods and inoculation or augmentative release programs with resident natural enemies.

Kent Daane is Post-Doctoral Researcher, and Leopoldo Caltagirone is Entomologist, Division of Biological Control, University of California, Berkeley. *Funding for this research was provided by the California Olive Committee and the Division of Biological Control. The authors thank L. Ferguson, K. Hagen, C. Hill, C. Kennett, E. Kinsel, B. Krueger, M. Martin, F. Schiro, and S. Sibbett for assistance in project development and locating grower collaborators.*

Garlic weed competition

Harry S. Agamalian ❑ Edward A. Kurtz

If not controlled with chemicals or by costly hand removal, weeds can cut garlic yields in half and lower the quality of the crop. Field trials comparing chemical and hand removal showed that judicious use of selective herbicides combined with good cultural practices will achieve best results.

Garlic yields from weed-free rows (center) were as much as 50% greater than in rows in which weeds were not removed (left and right).

Garlic is grown on 15,000 to 17,000 acres in California for processing (dehydration) and fresh market use. It is a long-season annual crop (230-250 days), planted in the fall and harvested in the late summer of the following year. Consequently, the crop is vulnerable to competition from winter and summer annual weeds. Some of the more troublesome are Russian thistle (*Salsola australis*), little mallow (*Malva parviflora*), shepherd's purse (*Capsella bursa-pastoris*), London rocket (*Sisymbrium irio*), common groundsel (*Senecio vulgaris*), sowthistle (*Sonchus oleraceus*), and many grass species.

Early growth of garlic provides little shading to suppress weeds. In addition, all garlic for processing is mechanically harvested, and weeds interfere with equipment operation and bulb recovery.

Although several herbicides are registered for weed control in garlic, their value compared with removing weeds by mechanical or physical means is often questioned. However, garlic is planted at a high density of 16 to 22 plants per linear foot, and hand-weeding can be extremely costly.