Crop Profile for Walnuts in California

Prepared: September, 1998

General Production Information

- California produces 99% of the walnuts grown in the United States and 38% of the world's production (6).
- Bearing walnut acreage in California in 1997 totaled 177,206 acres with an additional 20,913 acres of non-bearing trees (10).
- From 1990-1994, California's average production was 235,600 tons. In 1995, the crop totaled 234,000 tons valued at $313,560,000 (6).
- Over 40% of the California walnut crop is currently being exported (6).
- Thirty-five percent of the crop is marketed inshell (6).
- The total cost to produce an acre of walnuts amounts to $3,022 (8).

Production Regions

The Sacramento and San Joaquin Valleys of California are the largest production areas. Acreage is well distributed throughout these regions. The coastal valleys in the counties of Santa Barbara, San Luis Obispo, Monterey, and San Benito also have significant production. Unique areas in the Sierra Foothills and Lake County also have some walnut production (6).

Post Harvest

Dried walnuts are fumigated after harvest with methyl bromide primarily for control of codling moth, navel orangeworm, and storage pests. Control of these insects is critical to maintain markets that demand insect-free walnuts. Some countries like Japan require fumigation of walnuts with methyl bromide prior to export to control pests (e.g., codling moth) that could be present. An alternative to methyl bromide is phosphine, but unfortunately it has the significant disadvantages of a longer treatment time (4 to 10 days or more as compared to 3 to 12 hours for methyl bromide resulting in costly delays in overseas shipments) and reduced activity at lower temperatures that can be a significant problem in the fall when walnuts are harvested. In addition, it has demonstrated resistance problems for some pests. Phosphine also costs twice as much as methyl bromide.

U.S.D.A.-ARS scientists at Fresno are currently investigating controlled atmosphere technology and the use of several promising candidate compounds (carbonyl sulfide, sulfuryl fluoride, and methyl iodide) as replacements for at least some of the current methyl bromide uses. These tests have just begun so it is too early to judge their potential usefulness for dried walnuts. None of the chemicals under test are

registered for use. The use of controlled atmosphere is very slow (e.g., 5 to 7 days or more) and would be extremely difficult to accomplish with large volumes of walnuts and existing storage facilities.

Other treatments such as cold or heat, irradiation, and biological control have not proved successful economically or logistically in insect disinfestation and in maintenance of product quality as practical replacements of methyl bromide.

Cultural Practices

Over 15 varieties of walnuts are grown in the state commercially, with numerous other cultivars being planted on a smaller scale. Selected cultivars are grafted onto rootstocks. The three rootstocks generally used in California are Northern California Black, Paradox hybrid, and English Walnut. Both varieties and rootstocks vary in susceptibility to diseases, nematodes, and insect pests.

Walnuts are ideally suited to deep, well-drained, fine sandy loam to clay loam soils. Walnuts will not produce adequate commercial crops without irrigation in most California growing areas. Flood, furrow, and sprinkler irrigation are predominant with drip and micro-sprinkler irrigation being used more often, especially in marginal soils. Non-cultivation of orchard soils with herbicide-treated tree rows is common. Mechanized winter pruning is practiced and well suited to these sod orchard floor techniques with drip, micro, and sprinkler irrigation. A smooth orchard floor is necessary to facilitate harvest of walnuts that are shaken to the ground, swept into a windrow, and picked up with pickup machines. Some orchards are disked and rolled before harvest to insure a smooth, firm surface for harvest.

Insect Pests

Codling Moth, *Cydia pomonella*

Codling moth is the key pest of walnuts and is the most economically important insect pest statewide and must be controlled in many early-blooming varieties. Approximately 60% of the acreage planted in California is susceptible to damage from codling moth and require from one to three treatments every year to prevent serious economic damage. There are indications that codling moth is adapting to heretofore tolerant cultivars so the percentage of susceptible acreage will probably increase.

Codling moth larvae damage nuts by boring into nuts and destroying the kernels, rendering them worthless for commercial use. Codling moth overwinter as prepupae on the tree or in the soil around the base of the tree. In the early spring, adults emerge from over-wintering larvae, lay eggs giving rise to larvae that enter developing nutlets. Later generations either bore directly into the nut or enter the nut at the stem end after the hull hardens. Adult codling moth are about ½ inch long, gray in color with a prominent copper spot on the end of the forewings. Codling moth larvae are whitish to pink in color with

mature larvae being about 3/4 inch long. There are usually three generations per year in the central valley of California, but a partial fourth generation may develop in warmer than normal years (2). In addition to direct crop loss of infested nuts, growers suffer increased penalties as the percent infestation rises because of elevated sorting costs. Codling moth infested nuts act as a food bridge for navel orangeworm and allow infestations to build up inside the orchard. If left uncontrolled, damage can exceed 40%. **Monitoring:** Codling moth is monitored with pheromone traps which are utilized to assess population levels and calculate degree days for timing treatments. Dropped nuts and previous years grade sheets are also utilized in making treatment decisions (5).

Controls

Biological

Although over 250 biological control organisms have been shown to attack codling moth, none are capable of keeping populations below that which causes economic damage. Codling Moth Granulosis Virus has been shown to be somewhat effective. It must be eaten by larvae and from 9 to 12 applications are needed each year to cover the long generation time (5). Timing these treatments is extremely difficult because irrigation scheduling prevents growers from getting into orchards in a timely matter. Also, because walnut trees are large, it is not possible to get the thorough spray coverage with this material necessary for reliable control.

Trichogramma platneri,a codling moth egg parasite, has reduced codling moth damage by up to 70% when 12 weekly releases of 150,000-200,000 per acre per week are released in low to moderate population situations (5). This level of control is not adequate to prevent a buildup over time and economic damage in most walnut orchards in the state.

Codling moth mating disruption is not economically feasible in walnuts because of large tree size and the large volume of air which would have to be permeated with pheromone (4).

Chemical

Approximately 60 percent of walnuts in California are treated from 1 to 3 times (average 2 times) during the growing season for codling moth. Because of multiple treatments in some blocks, the percentages given below will total over 100% (60% of orchards treated X 2 treatments).

Azinphos-methyl - 21 days PHI. Applied, usually once postbloom, to 35% percent of the acreage by ground at an average rate of 2 lb. a.i. per acre (1). Some levels of codling moth resistance have recently been documented in walnuts in California (7). This is still a valuable material in spite of pockets of resistance because the long residual covers the long codling moth hatch. Recent research shows that beneficials tolerate this material.

Chlorpyrifos - 14 day PHI. Used primarily for codling moth. Applied at least once to 40% of the walnut

acreage by ground at the rate of 1.75 to 2.0 lb. a.i. per acre (1). Recent data indicate that azinphos-methyl resistant codling moth may exhibit negatively correlated cross-resistance with chlorpyrifos, making this a valuable material in managing organophosphate resistance in walnuts (7). It has a short residual and does not cover the entire egg hatch period. Chlorpyrifos also controls walnut aphid, soft scales, and walnut husk fly if properly timed (5).

Esfenvalerate - 21 day PHI. Applied postbloom once to 5% of the acreage by ground at .05 lb. a.i. per acre (1). This material is very disruptive to the biological control of mites and should only be used late in the growing season (5). Also used for navel orangeworm and walnut husk fly (5).

Permethrin - 1 day PHI. Applied postbloom once to 10% of the walnut acreage by ground at the rate of .25 lb. a.i. per acre (1). Extremely disruptive to biological control of mites and not used in the San Joaquin Valley because of this problem. Should only be used late in the season (5).

Tebufenozide - 30 day PHI. Applied postbloom once or more to 15% of the acreage by ground at the rate of .25 lb. a.i. per acre (1). A high priority material. The need for good coverage and big trees limits the utility of this material. Fits well in an IPM program.

Diflubenzuron - 28 day PHI. Applied postbloom one or more times to 12% of the walnut acreage by ground at the rate of .25 lb. a.i. per acre (1). A high priority material. May cause aphid outbreaks, but is not common. The need for good coverage and big trees limits the utility of this material. Fits well in an IPM program. This material cannot be used with *Trichogramma* inundative release or importation of natural enemies.

Phosmet - 14 day PHI. Registered for use on walnuts in 1996. Use data for 1996-97 is not available, but it is believed as much as 25% of the walnuts in California were treated during that period. Use rate is 2.1 to 4.2 lb. a.i. per acre (1). Less disruptive to beneficial mites and arthropods than some other organophosphates. Used in walnut orchards where proximity to nonagricultural activity and native wildlife habitat necessitate use of a pesticide with minimal impact on non-target organisms. Late season applications will control walnut husk fly and navel orangeworm if properly timed.

Methyl-parathion - PHI 14 days. Received a SLN for walnuts in California in 1997 and use data is not available at this time. Applied postbloom by ground at the rate of 1.5 to 2.0 lb. a.i. per acre. Maximum of 8 lb. a.i. per season. Recent data indicate that azinphos-methyl resistant codling moth may exhibit negatively correlated cross-resistance with methyl-parathion, making this a valuable material in managing organophosphate resistance in walnuts (7). It is anticipated this material will be applied to significant acreage in response to the development of azinphos-methyl resistant codling moth, particularly in the southern San Joaquin Valley.

Diazinon (see walnut aphid) and **Methidathion** (see scale) will also control codling moth.

Navel Orangeworm, *Amyelois transitella*

This scavenger insect attacks a wide range of walnut varieties; feeding directly on the kernel inside the nut. It not only destroys kernels, but may be associated with fungi responsible for aflatoxin. Navel orangeworm larvae cannot enter sound nuts so damage occurs after hullsplit and before harvest. Navel orangeworm overwinters as larvae inside mummy nuts left on the tree and in trash nuts left on the ground. Silver gray moths of the overwintered brood emerge in spring and lay eggs on nuts damaged by codling moth or blight which act as a food bridge for this generation. After hatching, white neonate larvae of the first generation enter nuts damaged by codling moth or walnut blight, making codling moth and blight control extremely important. Larvae mature inside nuts producing large amounts of frass and webbing. Mature larvae are white or pinkish and may reach 5/8 inch in length. After hullsplit, adults lay eggs directly on the hull of sound nuts and the tiny larvae enter nuts through the soft tissue at the stem end and do not emerge until they are adults (5). There are 3 to 4 generations per year. Twenty percent damage is not uncommon in late harvested orchards. Monitoring: Egg traps are used to monitor navel orangeworm (NOW) and give some indication which blocks should be harvested earliest (2). Egg traps do not work well under high population pressure.

Controls

Biological

Two introduced wasps, *Goniozus legneri and Pentalitomastix plethoricus,* are established in many areas but are not effective in controlling NOW in walnuts (5).

Cultural

Control codling moth and walnut blight to eliminate these sources for 1st generation larvae and preclude an early buildup inside the orchard (2).

Shake mummy nuts from trees and flail all sound nuts on the orchard floor to reduce overwintering populations. In addition, good sanitation is a must around hullers, bins, dryers, and buildings where nuts have been handled.

Early and rapid harvest, including use of Ethephon to promote early harvest, prompt drying, and fumigating will all help reduce damage by NOW (2).

Chemical

Chemicals are an important part of a 3-step program for managing navel orangeworm in walnuts and provide 50-70 percent reduction if used correctly (2).

Azinphos-methyl - 21-day PHI. Applied postbloom to 10% of the acres by ground at an average rate of 2 lb. a.i. per acre (1).

Esfenvalerate - 21 days PHI. Applied postbloom to 19% of the acreage by ground at .05 lb. a.i. per acre (1). Can be used close to harvest. This material is very disruptive to the biological control of mites and should only be used late in the growing season. Also used for codling moth and walnut husk fly (5).

Carbaryl - 0 days PHI. Applied postbloom to 2% of the acreage by ground at 4 lb. a.i. per acre (1). Best used late in the season because it causes mite buildup (5).

Phosmet (see codling moth) will also reduce navel orangeworm.

Walnut Husk Fly, *Rhagoletis completa*

Walnut husk fly is a direct pest of walnuts. This fly attacks all varieties and is most damaging on mid and late season walnuts, especially those marketed inshell. Larvae feeding in the husk cause darkening of the shell, and shrivel and mold on the kernels. Adult husk flies are about the size of a housefly and very colorful with characteristic bands on the wings. They overwinter as pupae in the soil and emerge in mid summer. Females deposit a clutch of eggs just below the surface of the husk. White maggots emerge from the eggs and feed in the husk causing the husk to become mushy and black. Mature larvae are yellow about 1/4 inch long. When mature, they drop to the ground, bore into the soil and pupate. There is one generation per year (2). Fifty percent damage can occur in some varieties if not controlled, but they are not a problem in the San Joaquin Valley at this time. Monitoring: Adult flies are monitored using yellow sticky traps to detect emergence. Examine for eggs to determine when egg laying begins (2).

Controls

Biological

A number of parasites have been introduced. At least one species has been recovered in small numbers, but has no impact on husk fly numbers.

Chemical

If a corn hydrolozate is combined with insecticide, alternate row treatments are effective, thus reducing the pesticide needed by one-half. Eighty percent of the acreage treated for husk fly use the bait plus insecticide combination (1).

Malathion - PHI 1 day. Applied postbloom by ground or air to 8% of the acres in July or August

at the rate of 1.75 lb. a.i. per acre (1). Has been implicated in inducing mite buildups.

Esfenvalerate - PHI 21 days. Applied postbloom by ground or air to 3% of the acres in July or August at the rate of .05 lb. a.i. per acre (1). Can increase mite problems (5).

Phosmet (see codling moth) and Diazinon (see walnut aphids) will also control walnut husk fly. Bait can also be added to late season codling moth treatments when damage is expected through monitoring.

Aphids:

Walnut Aphid, *Chromaphis juglandicold*

Dusky-veined Aphid, *Callaphis juglandis*

These occasional pests frequently build up to numbers adequate to cause stress on new leaf and walnut growth by extracting large amounts of leaf fluids. The walnut aphid was historically a major pest in walnuts until the successful introduction of a wasp parasite, *Trioxys pallidus.* This allowed dusky-veined aphid to become the dominant species in some orchards. Walnut aphids are greenish, much smaller than the dusky veined aphid and typically found scattered on the lower side of the leaf, whereas the dusky-veined aphid feeds in rows along the midvein. Both species overwinter in the egg stage on the tree. After overwintered eggs hatch in early spring, aphids begin feeding on the leaves and reproduce without mating, giving birth to living young. The aphids have many generations in a year and can build up to several hundred per leaf. In addition to the debilitating effect of aphid feeding, heavy infestation can cause almost complete defoliation and sooty mold growing on honeydew can cause severe sunburn on the nuts (2). High populations can cause yield reductions of 25%. Monitoring: Both species are monitored by leaf counts. An average of 15 or more aphids per leaf requires treatment (2).

Controls

Biological

A parasitic wasp, *Trioxys palladus,* was introduced into California in the late 60s and brought walnut aphid populations to low levels. Unless disrupted by pesticides or abnormal weather, this parasite keeps walnut aphids at very low levels. Generalist predators such as ladybird beetles, green lace-wings, earwigs, and minute pirate bugs prey on dusky-veined aphids keeping populations below damaging levels in many situations (2).

Chemical

Research has shown that economic damage can occur and chemical treatment is warranted if aphid numbers exceed 15 aphids per leaflet (2).

Endosulfan - PHI not after hullsplit. Applied postbloom to 1% of the acreage by ground at the rate of 2 lb. a.i. per acre (1). A selective material that does not disrupt biological control of mites and aphids. Preferred material where it can safely be used. Toxic to fish if it drifts into waterways.

Oxythioquinox - PHI 30 days. Applied postbloom to 1% of the acreage by ground at the rate of 1.5 lb. a.i. per acre (1).

Diazinon - PHI 45 days. Applied postbloom by ground to 2% of the acreage at the rate of 2 lb. a.i.. per acre (1). Will help control armored and soft scales if properly timed (5). A selective material that is not disruptive to biological control of mites and aphids. Will also control husk fly if properly timed.

Mites:

Twospotted Mite, *Tetranychus urticae*

Pacific Mite, *Tetranychus pacificus*

European Red Mite, *Panonychus u1mi*

Although European red mite can build up to high numbers, it is seldom considered a serious pest. However, both twospotted and Pacific mites can cause almost complete defoliation which exposes trees and nuts to sunburn, reduces nut size, and can interfere with harvest. Pacific and twospotted mites overwinter as adult females in the trees or on the orchard floor. Both species are favored by hot, dry conditions and as the weather becomes warmer, they increase in numbers and move throughout the tree (2). Severe defoliation early in the season can cause a 25% reduction in yield. As the season progresses, the potential for direct damage decreases. Monitoring: Mites are monitored by counting the number of infested leaf clusters.

Controls

Biological

Predators are important in keeping mite levels below damaging levels. The most dependable predator is the Western Orchard predator mite, *Metaseiulus occidentalis,* which, if not disturbed by some pesticides applied for other pests, can usually keep populations below damaging levels in well-managed orchards. *M. occidentalis* is resistant to most organophosphates and insect growth regulators used for codling moth control, but extremely susceptible to synthetic pyrethroids and

carbamates (5). Other important predators include sixspotted thrips, minute pirate bug, and a small beetle, the spider mite destroyer.

Cultural

Minimize dust by oiling orchard roads and maintaining a well-managed ground cover. Well irrigated, vigorous trees are less susceptible to mite damage (2).

Chemical

If 10% of the trees have brown leaf clusters caused by mites and no predators are present, a chemical treatment is warranted (2).

Narrow Range Oils. PHI 0 days. Applied postbloom by ground to 12% of the acres at the rate of 2 gallons per acre (1). Must be used with caution because of potential phytotoxicity if trees are stressed or dry (5). A selective material. Fits well in the IPM program if predator mites are present. Will also suppress aphids.

Propargite - PHI 21 days. Applied postbloom by ground to 25% of the acres at the rate of 1.8 lb. a. i. per acre (1). Does not disrupt biological control of mites and aphids. Fits well in an IPM program. Pacific mite is resistant in the southern San Joaquin Valley.

Fenbutatin-oxide - PHI 14 days. Applied postbloom by ground to 20% of the acres at the rate of .5 lb. a.i. per acre (1). Does not disrupt biological control of mites and aphids. Fits well in an IPM program. Does not work well in cool weather.

Dicofol - PHI 14 days. Applied postbloom by ground to 1% of the acres at the rate of 1.5 lb. a.i. per acre (1). Kills predaceous mites.

Chofentezine - PHI 30 days. Applied postbloom by ground to 6% of the acres at the rate of .12 lb. a.i. per acre (1). Does not disrupt biological control of mites and aphids. Fits well in an IPM program.

Armored Scales:

San Jose Scale, *Quadraspidiotus perniciosu*

Walnut Scale, *Quadraspidiotus juglansregiae*

Scale insects occasionally build up to numbers capable of reducing shoot and nut growth. Large populations may result in the loss of fruiting wood and the production of small-sized walnuts.

Scale insects suck plant juices from the inner bark by inserting their mouthparts into twigs and branches. Infested branches stop growing and heavily infested branches and fruit spurs will die. San Jose scale can kill scaffolds. Both species are covered by a small, gray shell that makes control difficult. If the shell covering is removed, the small yellow body of both species can be seen (2). Newly hatched nymphs move from under the shell and settle on branches and twigs. The best time to control scale is after hatching until the covering is well developed. San Jose scale has 3-5 generations per year while the walnut scale has 2. Heavy populations may reduce production by as much as 10% if left uncontrolled. Monitoring: Look for the presence of scales on twigs and branches (2).

Controls

Biological

Several natural enemies tend to hold armored scale populations in check. Two predaceous beetles, the twice-stabbed ladybird beetle, *Chilocorus orbus* and *Cybocephalus califomicus,* often occur in

large numbers and can keep low to moderate populations in check. Two parasitic wasps, an *Aphytus sp.* and *Prospaltella sp.* also help as a barrier to population increase. However once populations are high, these natural enemies may not respond fast enough to prevent damage and sprays are needed (2).

Cultural

Prevent dust which interferes with parasites.

Chemical

Because armored scales spend most of their life protected beneath the scale covering, correct timing is important.

Methidathion - 7 day PHI. Applied either dormant or postbloom to 9% of the acres at the rate of 2 lb. a.i. per acre (1). Will help control codling moth (5). Disruptive to biological control of mites and aphids. Must be used with oil or an additive, therefore can be phytotoxic when used during the dormant period.

Diazinon (see aphids) and Chlorpyrifos (see codling moth) will help control scale insects.

Soft Scales:

Frosted Scale, *Parthenolecanium pruinosum*

European Fruit Lecanium, *Parthenolecanium corni.*

Soft scales suck plant juices from leaves and twigs. Low to moderate populations apparently are not damaging, but heavy populations reduce terminal growth and vigor interfering with photosynthesis resulting in smaller nuts and poor kernel quality. Both species have one generation per year, overwintering in the nymphal stage on twigs. In the spring they grow rapidly, become convex in shape, secreting copious amounts of honeydew and the frosted scale secretes a frost-like wax on the cover (2). Considered minor pests but can cause up to 10% crop loss if populations are severe. Monitoring: Examine previous season's growth on randomly selected trees. If more than five nymphs per foot of wood and no parasites are present, a treatment is warranted (2).

Controls

Biological

Several species of parasitic wasps play important roles in regulating soft scale populations. The most important of these are *Coccophagus, Encyrtus,* and *Metaphycus* Spp. (2). However, parasites seem to cycle and soft scales become widespread every 10 years or so.

Chemical

For chemical treatments to be effective, they must be applied in the spring before rapid growth of overwintered nymphs begin (5).

Methidathion - 7 day PHI. Applied either delayed dormant or late summer to 3% of the acres at the rate of 2 lb. a.i. per acre (1). Will help control codling moth (5). Disruptive to biological control of mites and aphids.

Fall Webworm, *Hyphantria cunea*

Larvae of the fall webworm feed inside silken tents skeletonizing leaves reducing photosynthesis and exposing nuts to sunburn. They are pale brown or gray caterpillars with long hairs covering the body. Fall webworms overwinter as pupae and emerge in late summer. There is one generation per year. Infestations are localized and usually are controlled by insecticides applied for other pests (2). Heavy populations can almost completely defoliate trees and could cause 20% yield reduction on 5% of the acreage. Monitoring: Webworms are monitored for their presence by looking for silken tents.

Controls

Chemical

Fall webworm is usually controlled by insecticides applied for other pests. Tents must be wetted thoroughly for insecticide to penetrate.

Diazinon - PHI 45 days. Applied postbloom by ground to 1% of the acreage at the rate of 2 lb. a.i. per acre (1). Will help control armored and soft scales if properly timed (5). A selective material that is not disruptive to biological control of mites and aphids.

***Bacillus thuringiensis* - PHI 0 days. Various formulations applied postbloom at label rates by ground to 1% of the acres when larvae are present (1).**

Phosmet and Chlorpyrifos (see codling moth) will also control this pest.

Redhumped Caterpillar, *Schizura concinna*

Larvae of redhumped caterpillar are yellow with longitudinal reddish and white stripes. The head and fourth abdominal segment are red. They pass the winter as pupae in the soil and there are three generations per year. Larvae feed on leaves and heavy populations can cause severe defoliation resulting in sunburned nuts and small nut size caused by photosynthetic reduction (2). Most damag-ing to young trees, but can cause 5% yield loss if left uncontrolled.

Controls

Biological

Two parasitic wasps, *Hypersoter sp.* and *Apanteles conglomerates,* are important in regulating redhumped caterpillar populations. Generalist predators such as spiders, lacewings, bigeyed bugs, and damsel bugs also prey on larvae (2).

Chemical

This pest is easily controlled by ground or air applications.

***Bacillus thuringiensis* - PHI 0 days. Various formulations applied postbloom at label rates by ground to 1% of the acres when larvae are present (1).**

Diazinon - PHI 45 days. Applied postbloom by ground to 1 % of the acreage at the rate of 2 lb. a.i. per acre (1). Will help control armored and soft scales if properly timed. A selective material that is not disruptive to biological control of mites and aphids.

Phosmet and Chlorpyrifos (see codling moth) will also control this pest.

Diseases

Amillaria Root Rot,*Armillaria mellea*

The severity of this fungus disease depends on the rootstock and the strain of *A. mellea.* The pathogen invades the roots, crown and basal trunk, eventually girdling the crown region and destroying the entire root system causing death of the tree. Symptoms of the disease are creamy white, fan-shaped plaques of fungal mycelia beneath the bark. After rains in the fall or spring, a cluster of mushrooms often appears at the base of infected trees. The fungus develops most rapidly in moist cool soil. It can survive for many years in dead or living roots of many different species of trees. Generally, clusters of trees may be infected at one or several sites in the orchard (2). A localized problem but can cause 25% yield loss in infected orchards.

Controls

Cultural

Choice of rootstock is important in managing *A. mellea.* Northern California black walnut rootstock and Paradox hybrid are considered resistant, but in recent years have been infected in some areas. If the use of methyl bromide fumigation is suspended, infection of these rootstocks is expected to increase. English or Persian walnut rootstock is very susceptible to *A. mellea* and should not be planted where *A. mellea* is a problem.

Chemical

Methyl Bromide has shown some promise for control of *A. mellea* at the rate of 300-600 lb. per acre applied by injection with tarping. It is recommended that a deep-rooted covercrop be grown on the soil to dry it out completely before treating. Even under these conditions, eradication is difficult and this material is not widely used for *A. mellea (6).*

Crown Gall, *Agrobactefium tumefaciens*

Although crown gall can affect established orchards, the disease is most damaging to young trees. If left unchecked, crown gall may progress around the crown weakening and eventually girdling the tree. Young galls are smooth; as they age, they become rough and increase in size. Old galls are dark, brittle and cracked. The pathogen usually infects through wounds and young trees in nurseries are particularly prone to infection because of the many potential injuries during rearing and digging (2). If left uncontrolled and trees become stunted, losses of 50% can occur.

Controls

Biological

Agrobacterium radiobacter-84 **is a biological control agent used as a spray or dip on 85% of nursery trees after digging and before planting in the field (6).**

Cultural

Black walnut is much more tolerant than Paradox hybrid, although neither is totally resistant.

Avoid excessive root injury in young trees or during cultivation (2).

Chemical

Gallex™is used to selectively kill tumors on individual trees in existing orchards. The treatment is most effective when used on trees 4 years old or less. This procedure is expensive and difficult to carry out (5).

Phytophthora Root and Crown Rot, *Phytophthora spp.*

About 10 different *Phytophthora* species attack walnut trees. The pathogen enters the tree either at the crown near the soil line, at the major roots or at the feeder roots, depending on the species. Trees affected with *Phytophthora* first show small leaves, sparse foliage, and lack of terminal growth. Infected trees may decline for several years or die within the same growing season in which the foliage symptoms first appear. *Phytophthora* can survive in the soil for many years and spreads and infects the trees during moist cool to moderate temperatures in spring and fall, and some infection may occur in the summer depending on species (2). A localized problem affecting 20% of the orchards. Yield losses of 50% can occur in infected orchards.

Controls

Cultural

Rootstocks vary in susceptibility to the different *Phytophthora* species; none are resistant to all species. In general, Paradox rootstock is more tolerant than northern California black walnut. Plant on soil with good surface and internal drainage. Plant on ridges to keep standing water from around the base of the trees and manage irrigation to minimize soil saturation (2).

Chemical

Metalaxyl - Applied to the soil as a drench on <1% of the acreage (1,4). Little use in walnuts and effectiveness limited to small trees.

Walnut Blight, *Xanthomonas campestris* p.v. *juglandis*

Walnut Blight, a bacterium, is the major disease affecting leaves and nutlets of walnuts. Walnut blight is spread by wind-blown rain drops, sprinkler water, or pollen. The severity of blight each season depends primarily on overwintering populations of the walnut blight pathogen in dormant walnut buds and the presence of free moisture. The bacteria move and infect only when suspended in water. The bacteria survive the winter in dormant buds, catkins, and twig cankers. In early spring, the pathogen enters plant tissue through natural openings infecting leaves, shoots, pistillate flowers, nuts, and catkins. In early season, infected female flowers shrivel and drop from the tree. Later, infected nutlets develop a dark lesion usually at the blossom end; most of these also drop. As nuts mature, lesions can develop anywhere on the husk surface causing kernels to shrivel or darken which renders them unmarketable. These later infected nuts often harbor navel orangeworm. All walnut cultivars are affected, but it is most serious on early blooming cultivars (2,6). If not controlled, yield losses can exceed 50% in wet, warm years. In orchards where copper tolerant bacteria are prevalent and Maneb + zinc is not available or used, 70% yield losses can occur (4).

Controls

Chemical

The disease is difficult to control because the bacteria are protected inside dormant buds and catkins. Control of walnut blight is based on spraying copper compounds repeatedly to protect new tissue as it emerges. The number of treatments varies depending on varieties, the length of the rainy season, and history of the orchard.

Copper (Various Formulations). Although air applications are somewhat effective, copper is generally applied by ground because good coverage is necessary. Applied 1-8 (average 2.5) times on 75 percent of the acreage in the state at the rate of 4 lb. a.i. per acre per application(1,4). Resistance to copper is not uncommon in the Sacramento Valley and has been found in a few sites in the San Joaquin Valley (5).

Maneb - Combined with copper to improve control, primarily in the Sacramento Valley, where copper resistant walnut blight has been detected. Applied by ground to 33% of the acres at the rate of 1 lb. a.i. per acre per application (1, 4). The addition of Maneb + Zinc to fixed copper sprays reduces blight infection by approximately 50% as compared to copper sprays alone. Maneb + Zinc and fixed copper Section 18 registration was obtained from 1994 through 1998. To date, no suitable alternative treatments are available for use on walnuts.

Nematodes

Lesion Nematode, *Pratylenchus vulnus*

Ring Nematode, *Criconemella xenoplar*

Root Knot Nematode, *Meloidogyne spp.*

Plant parasitic nematodes are microscopic roundworms that feed on plant roots of most plants including walnuts. They live in soil or within the cortical tissues of the roots. The extent of the damage caused by nematodes in walnuts depends largely on the density of the nematode population, soil conditions, and rootstock selection. The root lesion nematode builds to its highest population levels on walnut roots and a hypersensitive response by the plant results in a distinct decayed lesion on invaded roots. The severity of this nematode is age dependent with up to 50% losses in vigor of older trees to almost complete loss in replanted, sandy loam soils where the trees are not started out correctly in the first place. In situations where tree growth has been visibly impaired by the second year, the affected trees may never overcome the nematode problem. Symptoms of a nematode infestation include lack of vigor, small leaves, dieback of twigs, and a sparse root system, particularly the lack of small feeder roots. Root galls are an indication of root knot nematode. Black walnut rootstocks are a good source of resistance to the root knot nematodes, whereas English walnut parentage can carry a high degree of susceptibility to this nematode. As much as 85% of the walnut acreage has root lesion nematode present, with greatest damage expected during replanting. The root knot nematode is less prevalent with damage primarily expected on the sandier soils. The ring nematode causes damage by pruning the rootlets of walnuts. It is most abundant in the same soils that support root knot nematode. It is root lesion nematode that is most important to walnut growers, but breeding programs and the development of pest management strategies must also give attention to these other two nematodes.

Controls

Biological

There are no known biological agents that are deliverable to soil or the surfaces of roots that will provide relief from endoparasites such as root lesion nematode. Metabolites produced by myrothecium fungus were recently registered as nematocidal. Performance of this product is highly variable in small plots and there is much about this biologically derived product that is not understood. This product is now receiving commercial evaluation in three walnut groves.

Cultural

Nematode numbers are greatly reduced for as long as six years by fallowing one or two years and

then fumigating prior to replanting. The fumigation serves the important function of killing all the remaining roots within the surface 5 feet of soil profile. Without fumigation, these roots could remain alive four years after the old trees have been removed and soil deep-ripped. Few growers could afford to idle their land for the 4 to 5 years necessary to achieve adequate relief from the replant problem plus root lesion nematode. Paradox hybrid rootstock exhibits greater tolerance to the root lesion nematode than do the black seedling rootstocks. However, it will also exhibit dramatic damage by high populations of root lesion nematode (2, 6). The anticipated loss of methyl bromide has prompted the walnut industry to search for other methods that result in death of the remnant roots. By cutting off trees at their trunks and painting the cambial region with Triclopyr systemic herbicide, it has been possible to completely kill the roots so that 18 months after such a treatment, one can replant without experiencing the replant problem (3). At this point in time, none of this work has been conducted on trees older than six years and it only provides one year of nematode relief, but in concert with other nematode-controlling strategies, this methodology may replace some of the need for soil fumigation. Once trees are established, there are no effective methods for nematode control except for methods such as cover cropping to improve soil structure, thereby reducing tree stress.

Chemical

Methyl Bromide is used as a preplant treatment when replanting into soils previously in orchard crops. It is applied one to two feet deep, usually with a plastic tarpaulin stretched over the field surface. In 1995, 35% (1,360 acres) of newly planted walnuts were treated (1, 3, 4). In order to save on costs, growers in some regions may treat only the planting strips or the individual planting sites, with or without use of a tarp. These latter treatments only provide up to two years of nematode relief, which is adequate for the best silty loam soils. The usual treatment rate for walnuts is 400 lb. per acre. An estimated 80% of soils replanted to walnut receive a treatment, although the pounds used may be as low as 50 lb. per acre for spot treatments which could account for half of all treatments. There are no effective postplant nematocides and no rootstocks are known to be resistant to root lesion nematode so growers make a critical decision whenever they decide on a partial fumigation or to not fumigate at all. The damage by nematodes is severe enough on walnut that without methyl bromide or an effective alternative, the resulting orchards will be weaker with fewer roots and any damage with above ground pests will be increased.

1,3 Dichloropropene is the closest replacement for methyl bromide, but its use in California was suspended from 1990 to 1996 and today there are serious acreage restrictions and a limitation of 350 lb. per acre associated with its use. Use data are not available at this time. Excessive volatilization has been the key shortcoming to its recent use and the walnut industry has been searching for improved methods of application to limit in-field volatilization without jeopardizing efficacy. Prior to 1990, the normal treatment rates for 1,3 Dichloropropene were from 400 to 800 lb. per acre largely because walnuts are grown on finer-textured soils, compared to other tree crops. Newer methods of killing roots plus the lowered rates of 1,3 Dichloropropene plus the use of a water seal containing Metham-sodium biocide will soon receive field evaluation as a methyl bromide alternative, but it is premature to predict the results in commercial settings (3).

Weeds

In addition to problems at harvest, weeds can cause a multitude of other problems in walnut orchards by reducing the growth of young trees because they compete for water, nutrients, and space. Weeds also increase water use, cause vertebrate and invertebrate and other pest problems, and may enhance the potential for disease. The increasing use of more efficient low-volume irrigation systems has increased the need for selective pre-emergence herbicide use in drip, microsprinkler, and sprinkler irrigated orchards. Herbicides are generally used only in the tree row. This reduces the total amount of herbicides and prevents the surface roots in the tree row from being damaged by cultivation equipment. Weed species are controlled by pre-emergence, post-emergence, or a combination of pre- and post-emergent herbicides. Soil characteristics have an effect on the weed spectrum (often 15-30 species per orchard), the number of cultivations and irrigations required, and the residual activity of herbicides. Irrigation methods and the amount of irrigation or rainfall affects herbicide selection and the residual control achieved. Monitoring: Treatment decisions and herbicide selections are based on dormant and early summer weed surveys.

Controls

Chemical

Glyphosate -PHI 3 days. Applied during the dormant, pre- and/or postbloom by ground one or more times per season on 75.8% of the acreage at an average rate of .8 lb. a.i. per acre (1). Nonselective systemic used for a broad range of weed species. Effective anytime on emerged, irrigated, rapidly growing, non-stressed weeds, but activity is slower in lower temperatures. Not effective on some broadleaf weeds at older stages of growth (malva and filaree). Continued use of this material leads to a shift of species and selection of tolerant species. Light activated spray technology has reduced the amount of material applied when weed cover is low by 50 to 80%.

Oxyfluorfen - 0 days PHI. Applied by ground one time per season on 26.5% of acreage at an average rate of .27 lb. a.i. per acre (1). Selective broadleaf herbicide effective as a pre- and post-emergent material. Particularly useful when combined with Glyphosate to increase efficacy on various broadleaf weed species and to prevent broadleaf species shifts with Glyphosate.

Simazine -21 day PHI. Applied anytime to bare soil or in combination with Glyphosate by ground one time per season on 17.7% of the acreage at an average rate of 1.3 lb. a.i. per acre. Pre-emergence herbicide of most annual grasses and many broadleaf weeds. Effective when combined with translocated herbicide such as Glyphosate or the contact herbicide Paraquat, and a broadleaf pre-emergence herbicide as in Oxyfluorfen. Typically used for down the row treatment to maintain clean row for irrigation emitters and season long weed suppression.

Diuron -0 days PHI. Applied winter through spring by ground one time per season on 12.4% of the acreage at an average rate of 1.05 lb. a.i. per acre (1). However, total rate is sometimes split into half with two applications. Pre-emergence used to maintain season long weed suppression down the row. Effective when combined with Simazine, Oxyfluorfen, or Sulfur.

Paraquat - 0 days PHI. Applied pre- or postbloom by ground one or more times per season on 12.3% of acreage at an average rate of .69 lb. a.i. per acre (1). Nonselective postemergence material used for quick burndown of most weed species. Less effective against perennials that will regrow with vigor, e.g., bermudagrass, dallasgrass, johnsongrass, and bindweed. Most effective when used on early spring or winter growth of annual weed species in combination with pre-emergence herbicides.

2-4-D -60 day PHI. Applied as a directed spray postbloom by ground one or two times at the rate of .13 lb. a.i. per acre (1). Postemergence systemic herbicide selective for most broadleaf annual weeds. Effective on field bindweed. Useful for controlling troublesome perennials when combined with Glyphosate or Fluzifop.

Oryzalin - 0 days PHI. Applied preemergence by ground one time per season on 5.4% of the acreage at the rate of 1.5 lb. a.i. per season (1). Pre-emergence selective herbicide most effective on annual grass species and numerous broadleaf annuals. Very safe for young or newly planted trees and on sandy or sandy loam soils. It is used to maintain control in strips down the row. Often used in combination with other pre-emergence herbicides.

Norflurazon -60 days PHI. Applied prebloom by ground one time per season on 2.9% of the acreage at the rate of 1 lb. a.i. per acre (1). Pre-emergence selective herbicide similar to Oryzalin, but is effective on more annual broadleaf and grass species. Can suppress yellow nutsedge or bermudagrass when used year after year. Can cause minor damage to younger trees or those planted on sandy or sandy loam soils. Usually used on new plantings.

Trifluralin -0 days PHI. Applied prebloom by ground one time per season on <1% of the acreage at the rate of 1.63 lb. a.i. per acre (1). Pre-emergence selective herbicide for annual grasses. It must be combined with broadleaf herbicides and incorporated promptly for best results.

Napropamide -0 days PHI. Applied prebloom one time per season on <1% of the acreage at the rate of 2.14 lb. a.i. per season (1). Pre-emergence herbicide effective on annual grasses and several annual broadleaves. Must be applied and incorporated with irrigation or rain within seven days. Very effective in maintaining weed free strips down the row.

Pendimethalin -Non-bearing trees only. Applied pre-emergence by ground one time per season at the rate of .5 to 1 lb. a.i. per acre. Effective on annual grasses and some broadleaf weeds. No use data available at this time.

On-Line Resources

Pests of Walnut

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