Bacterial blight \textit{(Xanthomonas campestris pv. juglandis; syn. X. arboricola pv. juglandis)}

\textit{Symptoms:}
- On all current season’s growth - older wood is not susceptible.
- On infected shoots there are dark lesions, 3-6 cm long.
- On leaves, brown to black spots, with lighter colour around the edges; with severe infection the leaves may drop.
- Infected catkins shrivel, darken and become distorted.
- Female flowers and nuts: first symptoms are small, water-soaked spots, which expand rapidly.
- Kernel infected before shell hardening will shrivel.
- Nuts infected at an early stage will drop prematurely. In older nuts the hull sticks to the shell with black, sunken areas on the surface of the hull and the kernel turns black.

\textit{Critical factors:}
- Varietal characteristics
- Weather conditions
- Aspects of management
- Timing of spray applications
- Chemicals

\textit{Varietal characteristics:} - earlier leafing and flowering varieties are more susceptible, because wet weather during bloom favours bacterial growth and spread. In areas with late spring rains, mid- or late flowering varieties may be a wise choice.

According to Californian experience:
- susceptible: Ashley, Payne, Sunland, Tulare (early leafing)
- susceptible in districts with wet spring: Vina (leafing 8 days after Payne)
- usually far less effected: Chandler, Hartley, Howard and Franquette (late leafing)
- less effected: Geisenheim 26 (very late leafing)

\textit{Weather conditions:}
According to recent Californian research results –
- Daily average temperatures between 12 – 20\degree C for 13 – 14 hours and extended leaf wetness 8 – 12 hours were most conducive to disease development. This research developed models to forecast period of infection
- Increased tree density – and also overhead irrigation, could prevent the drying effect of wind in the line and provide suitable conditions for the spread of the disease.

\textit{Aspects of management:}
The management program for blight focuses on preventing dispersal and development of the pathogen. Once infection has occurred, nothing can be done to stop bacterial growth at the site.
Adjustments in cultural practices include:
- using low-angle sprinklers to avoid wetting of foliage;
• avoiding irrigation during bloom; scheduling an irrigation during pre-bloom, if winter rains were not adequate;
• removing low-lying limbs that are apt to catch the water from the sprinkler;
• avoiding crowding from double-planting of two varieties by removing the variety that is more susceptible to blight;
• training young trees; heading the trees high to allow air movement under the trees and avoiding wetting low limbs;
• opening up trees during pruning to increase air movement through the tree;
• practice orchard hygiene: as far as feasible, collect and burn infected shoots and nuts.

Timing of spray application:
• First spray - infection is present in walnut trees throughout the year and the spread of infection at the start of the season depends on the level of over-wintering infection. This makes the timing of the first spray critically important. According to the latest Californian results, the first spray should be applied at the bud-break of the terminal pistillate flowers\(^1\). Effective blight control requires all susceptible surfaces to be protected by a bactericide. If possible, spray before there is rain. Spraying after rain only gives protection for subsequent rain that may follow.
• Second spray – when the first stigmas appear on the female flowers. This development usually coincides with the beginning of leafing.
• Third spray - when the stigmas of the first flowers dry up.
• In a low rainfall season, two to three applications during bloom may control blight, but in a wet season sprays repeated at 7 –10 day intervals through bloom, or until rainfall stops, are necessary.
• Follow-on sprays during summer - because of the importance of climatic factors, growers should install a rain gauge and a maximum-minimum thermometer. These should be regularly checked during the growing season and sprays should be repeated once there was a total 15-20mm of precipitation since the previous spray. Many failures can be attributed to the fact that the sprays during flower development are not followed up with sprays during active growth, whenever weather conditions are favourable for the spread of infection. Although an intensive spray program may not eliminate blight in a wet year, even a limited number of early sprays will reduce the damage.
• Final spray – at leaf fall, will help to reduce the number of over wintering bacteria.

Chemicals:
Copper sprays:
Formulations containing copper: Bordeaux mixture, copper oxychloride, cupric hydroxide ('Kocide'), cuprous oxide ('Nordox 500'). According to research conducted in California and in Tasmania recently, spraying with a combination of Kocide and Mancozeb (a manganese and zinc formulation) provided a more effective protection than Kocide on its own. In Australia the additional use of Mancozeb is now permitted through a minor use off label permit.\(^2\)

The amount of metallic copper recommended in California is 4.5 kg (about 18 kg/ha of copper sulphate). In a mature orchard the volume of the diluted spray to be used may vary between 3,000 to 9,000 l/ha, depending on the size of the trees. For concentrate spraying the range is 300 to 1,200 l/ha

Spray volume per hectare\(^2\):
The volume of dilute spray necessary for effective control is often calculated for the unit area (hectares), regardless of tree size or density of foliage in the canopy. For allowing for the size of the tree, the plant-row volume is used, which is calculated from the height and width of the tree and the total length of tree rows in a hectare. The spray volume factor (SVF) equals the number of litres of spray retained by 1000m\(^3\) of plant row volume sprayed to run-off. The SVF varies depending on the density of the foliage in the tree canopy (with dormant trees, there is a lower SVF than with trees in the middle of the growing season). To calculate the volume of spray needed per hectare, first determine the SVF from the following table:
Foliage density        SVF
Dormant trees         75
Low density (early season sprays)     100
Medium density       125
High density (mid to late season)     150

Then use the following formula (all measurements in metres):

\[
\text{Litres of spray/ha} = \frac{10 \times \text{SVF (tree height)} \times \text{(tree width)}}{\text{(distance between rows)}}
\]

This is the volume needed for high volume application. For low volume this has to be divided by the concentration factor.

\^2\text{From the Orchard pest and disease handbook, Deciduous Fruit Australia, 2000-2002, 10th edition, 2000.}

- Copper sprays are effective in controlling a wide range of bacterial and fungus diseases.
- They do not eradicate infection, but will provide protection of newly grown, soft tissue. Most copper sprays have a reasonably long residual life, having little, or no volatility, thus can give comparatively long periods of protection. Copper sprays are generally used as protectants and for satisfactory control good coverage is necessary before infection occurs (for conventionally planted, large old trees, special spray equipment may be necessary).
- Bordeaux mixture is a mixture of copper sulphate and lime. Copper sulphate is very soluble, with a short residual life and a high risk of phytotoxicity. The lime extends the residual life and reduces the risk of phytotoxicity – however, it makes the mixture highly alkaline and so incompatible with most modern insecticides and it leaves a very visible deposit on the target. Hydrated lime is the best form to use. Bordeaux mixture provides more persistent cover than the other copper compounds, but its preparation is more time-consuming (see below) and it has a tendency to block the spray nozzles.
- Copper oxychloride has been a standard copper product. It mixes readily and having a close to neutral pH, in contrast to Bordeaux mixture, it can be used with many modern insecticides.
- Cuprous oxide is another suitable alternative. Its rusty colour distinguishes any visible deposit on the crop from the bluish deposit of most other copper sprays.
- Copper hydroxide is the basis of Kocide. Because of the small particle and crystallite size, it covers a greatly increased surface area and its low bulk density leads to ease of formulation dispersion and tenacity to plant surfaces.
- The most successful and safer copper compounds are relatively insoluble and those such as copper, remain in suspension in a spray mix. The lower solubility leads to a much lower risk of phytotoxicity and much longer residual life.
- Most copper sprays leave a visible deposit on the crop – this could affect the photosynthesis of the leaves and can cause problems with heavy deposit on some type of fruit at harvest. Addition of oil to the Kocide spray will increase the tenacity of the deposit on the fruit.
- Copper sprays are phytotoxic to the tender parts of deciduous crops and recommended rates should be observed to prevent risks. Increased acidity of the solution will increase solubility and risk of phytotoxicity. Therefore the pH of the water used for spraying is of importance, as is the reaction of anything added to the sprays tank (some micronutrients could substantially reduce the pH of the solution).
Preparation of Bordeaux mixture:
- Prepare the mixture just before application (not more than 2-3 hours before use).
- Use plastic (not iron or galvanised iron) containers.
- Copper sulphate should be in fine crystal, or powder form, to dissolve easily; if it consists of coarse crystals, hot water will be necessary to dissolve it.
- Limil (hydrated or slaked lime) should be kept fresh, kept in sealed bags; once opened, the bags should not be kept for more than a two weeks and definitely not for the next season.
- Spreading and adherence to leaves is improved with summer oil (must be compatible with the copper compound used), or another suitable wetter and sticker. However, some growers believe using no wetter may reduce the spread of infection.
- For each 100 l of water the mixture consists of 500g of copper sulphate, 500g of Limil and 120ml of summer oil (the oil improves retention on leaves and may reduce risk of possible damage).
- Ingredients must be weighed accurately; if copper is in excess of lime, the spray may cause burn damage.
- When mixing, first dissolve the copper sulphate in the spray tank by washing it through the strainer (using 80 – 90 % of the total volume of water).
- Stir the Limil separately in a bucketful of water.
- Set agitator in motion and slowly pour the lime into the spray tank through the strainer and rinse the residue from the lime bucket.
- If using oil, mix it with equal quantity of water and add to vat.
- Add more water through strainer to get the full quantity needed.

Copper in the orchard environment:
- Build-up of copper residues in the orchard soil may have detrimental effect on the soil fauna (ladybirds). However, copper ions are readily bound up into a clay, or organic matter complex in a biologically inactive form and soils with a close to neutral, or alkaline pH are unlikely to have any such problems. Also, with regular copper sprays, plants should not suffer from copper deficiency.
- Copper sprays are of low mammalian toxicity and generally considered very safe to use. There is no withholding period required for their use before harvest and there is no maximum residue limit (MRL) in most markets.
- Symptoms of toxicity in animals grazing in walnut orchards, following regular use of copper sprays created suspicion with local growers and it is recommended that, where grazing is part of routine management, animals should only be allowed intermittently in sprayed orchards and also, the number of copper sprays applied, should be reduced, as feasible. Some deaths have been recorded in sheep flocks grazing heavily sprayed orchards.
- In several Californian orchards bacterial blight strains developed resistance to copper. Research has found that spraying with the combination of Kocide and Manex (a manganese and zinc formulation) provided a more efficient protection than Kocide on its own. Manex is not registered for use on walnuts in California, or Australia, but for the recent years the California authority yearly approved emergency registration in counties, where blight has developed copper resistance. (For more information on blight control, see the forthcoming AWIA publication on blight which will provide the latest up-to-date information for growers. Also see the documents from the 2011 Walnut Blight Control workshop available on the www.walnut.net.au website.)

Potential role of bacteriophages:
- Bacteriophages are specific plant viruses, capable of injecting one molecule into the infecting bacteria, due to enzymatic action. They may kill the bacteria, or become incorporated into it and prevent further infection. Research that started in New Zealand is continuing to identify the bacteriophages in walnut orchards, specific to blight strains. It is hoped that eventually a collection of such viruses could be cultivated and made available to growers as biological control agents.
Phytophthora trunk and root rots (also known as collar rot, or crown rot)

Several different Phytophthora species may attack walnut trees; among the two most common ones, *P. cactorum*, causes trunk rot and *P. cinnamomi* root rot and trunk rot.

Symptoms and damage:

Trees affected first show small leaves, sparse foliage and lack of normal terminal growth. The diseased tissue reduces the effective transportation of sap within the tree, resulting in gradual dying back of shoots and branches. During spells of hot weather leaves wilt, turn yellow and drop, exposing the nuts to sunburn. Infected trees may decline for several years – or die within the first growing season in which the symptoms first appeared. How soon the trees die after infection depends on the species of *Phytophthora*, climatic conditions and soil and water management. If diseased trees survive for several years, nut production gradually declines.

*P. cactorum* and *P. citricola* cause crown rot and trunk canker. A canker starts at one or several infection sites at the crown and spreads downward into the roots, or upward into the trunk, extending through the bark and cambium and staining the wood. The black sap may ooze from the dark brown bark. To confirm presence of crown rot, cut away the outer bark and look for a canker with water-soaked, dark brown concentric margins between healthy and infected tissue. The diseased tissue has a sour smell. - *P. cinnamomi* infects the crown and the entire root system. Decaying roots are firm and brittle, while those destroyed by excess water are soft and watery Once the base of the trunk is completely girdled, the tree dies.

Seasonal development – *Phytophthora* can survive in the soil for many years. The fungus spreads and infects the trees during moist, cool weather in the spring and autumn. During hot weather trees under stress become wilted.

Preventive and protective measures:

Selection of rootstocks – Northern California black walnut (*J. hindsii*) and the English walnut (*J. regia*) is susceptible, the Paradox hybrid is fairly tolerant to *Phytophthora*

Organic matter - incorporation of large amount of organic matter before planting will improve water permeability and may also help to establish colonies of micro-organisms, which are antagonistic to the fungus.

Ground cover - may improve water penetration and aeration of the soil, - factors important for a healthy root system. Also, a well-managed ground cover provides cooling and reduces dust, which often contributes to mite outbreaks. The cooling effect of the ground cover can be advantageous in areas with hot summers, but a disadvantage in areas with frost hazards. However, ground cover may compete with trees for nutrients and water, contribute to pest problems, weaken young trees, or interfere with sprinkler operation.

Control measures:

Eradication of *Phythophthora* from infected soil is very difficult and success of control of the spread of infection in the tree depends on early detection. Recently infected trees show slow bud development and shoot growth in the spring. Formulations containing phosphorus acid can be applied as sprays or injections as a preventive measure, or as control to contain the infection of affected trees.

Heavy mulching with chicken manure and straw or hay has been shown to be successful in improving soil biota which is antagonistic to phytoththora.
Crown gall (*Agrobacterium tumefaciens*)

In Australia crown gall is a significant bacterial disease on stone fruit and grapes, but its occurrence on walnuts is not as frequent here, as it is in California.

The bacterium infects roots and trunks, where it develops a hard, woody gall, with a rough surface. Galls may vary in size, usually many times the diameter of roots or stems in which they are grown. Infection usually occurs in nurseries, where, at the time of lifting, the roots become exposed, mechanical injury occurs and the tree can become infected. Also, it was found that infection is more likely where soil pH is 6.0 or higher.

Regulations prohibit the sale of infected young trees, and as a general precaution, all young trees, when lifted from the nursery, are dipped in the suspension of *Agrobacterium radiobacter* culture (Isolate 84). This biological control agent, a close relation of the organism causing crown gall, but antagonistic to it, was developed in Australia. Before planting out young trees, all roots should be examined and if there are roots with gall-like swellings, those trees should be rejected. As a precaution, on the day of planting, the roots should be dipped again in Isolate 84 to prevent re-infection.

Efficient dipping procedure:

- Follow the directions on the label.
- Use fresh (not chlorinated) water.
- Do not expose the culture to very high or freezing temperatures.
- Do not expose it to direct sunlight.
- Treated roots should not be allowed to dry out.

Armillaria or Honey Fungus (*Armillaria mellea*)

**Symptoms:**

*Armillaria* is a soil-borne fungus that will infect walnut trees if planted on infected sites. It is often found thriving on roots of native trees and when the land is cleared, the fungus survives in the rotting roots left in the soil. From there it spreads to the soil and newly planted trees. It is also known as bootlace fungus because its brown or black rhizomorphs resemble flattened shoelaces, which are attached to the bark of the roots. Tips of the rhizomorphs invade the roots and form fans which eventually kill the roots or girdle the crown of the tree. During summer after rain, a cluster of honey-coloured toadstools (fruiting bodies) may appear around the crown of infected trees.

**Control:**

In infected land – avoid recently cleared land. It is generally recommended that recently cleared land should not be planted to walnuts for approximately 10 years to avoid infection.

Trees should be planted with the graft union well above the soil surface to prevent infection of the scion.

**Rootstock resistance (Californian observations):**

<table>
<thead>
<tr>
<th>Rootstock</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>J. regia</td>
<td>highly susceptible</td>
</tr>
<tr>
<td>Paradox</td>
<td>variable</td>
</tr>
<tr>
<td>J. hindsii</td>
<td>highly resistant</td>
</tr>
</tbody>
</table>
**Blackline disease**¹

The disease is caused by infection of the walnut strain of the cherry leafroll virus that affects English walnut trees, however at this stage the virus has not been detected in Australia. Symptoms are similar to those caused by various soil borne pathogens, or scion-rootstock incompatibility, i.e., poor terminal growth, yellowing and drooping of leave and premature defoliation. The disease kills the tissues that transport nutrients and water between the rootstock and the scion. When the infection reaches the graft junction between the scion and the black walnut or Paradox rootstock, cells of the rootstock die. The dead cells form the characteristic black line that gives the disease its name. This layer of dead cells eventually girdles the tree and the scion will die. In addition, in Paradox rootstock a canker may develop, which extends into the rootstock.

The virus may be introduced into the orchard through grafting wood or pollen from infected trees. Within the orchard the pathogen is probably transmitted by infected pollen from infected trees, capable of transmitting the disease through flowers of healthy trees, receptive for pollination. Thus, indiscriminately applying foreign pollen in walnut orchards is not advisable. Spread of the pathogen through the soil by nematodes is unlikely, because black walnut and Paradox rootstocks are immune to the virus.

Trees may become infected at any age, but blackline is more common in trees 15 - 40 years old. After infection, trees decline over several years before dying. It was found in California that for 4 years no recognizable virus symptoms appeared on leaves of varieties known to be infected by blackline virus. Therefore newly planted orchards in areas subject to the disease should preferably be of high density of precocious varieties, which will start bearing relatively soon after planting.

B 4.2 Insect pests

**Codling moth** (*Cydia pomonella*)

Codling moth is the main insect pests of walnuts in Australia. It may be particularly damaging in the early flowering varieties, but the level of infestation will vary according to the season.

**Critical factors:**

- **Life cycle:** Codling moth over-winters as mature larva in silken cocoon under loose bark or in trash on the ground near the trunk of tree. The larva pupates early in the spring and adult moths appear in early October. Single eggs are laid on leaves near developing nuts or on the nuts. The time of hatching depends on temperature (between 5 to 20 days). The hatched young larvae bore through the blossom end of the immature nut and feed in the nut. The mature larvae leave the nut to pupate under loose bark or on the ground. Adults from the first generation emerge in December to lay eggs of the second generation. The newly hatched larvae bore into the walnut husk, where they mature. Some of the mature larvae leave the nuts for over-wintering, the rest develops into adults and produce a small third generation.

- **Type of damage:** Larvae of the first generation can be noticed by the frass at the site of entry into the developing nuts. These damaged nuts will fall from the tree. Larvae of the second and third generations often enter the husk where two nuts touch, or later, through the stem end. The damaged nuts remain on the tree.

- **Timing of control measures:** For living organisms there is a lower and higher developmental threshold indicating the temperature suitable for development. Measuring the heat above the lower developmental threshold accumulating over time provides a time scale, which is a meaningful indicator of the development.

   The unit of physiological time scale is the degree-day, defined as one degree above the developmental threshold maintained for a full day. For codling moth eggs, the lower threshold is 10°C and they require 160 degree days above this threshold to hatch. When 10°C accumulate every day, eggs hatch after 16 days – when 20°C accumulate every day, the eggs hatch after only 8 days.

   To calculate the Degree-Day:
   1. Add daily maximum and minimum temperatures and divide by 2. This is the average daily temperature.
   2. Subtract the lower threshold temperature (10°C for codling moth) from the average daily temperature. The result is the number of degree days accumulated that day.

   Pheromone traps, used extensively in pome fruit orchards, can also be used in walnuts. The scent of the attractant in the trap lures the male codling moth to the trap, where it is caught by the sticky surface. However the traps will not remove all male moths, only if the infestation is very light.

   Traps should be placed in the orchard early in October, at the rate of 1 trap per hectare and hung from an outside limb at shoulder height. The presence of moths must be monitored at least once a week, when the catch per trap should be recorded and the base cleaned. It may be worthwhile to place one or two traps outside the orchard to prevent movement of male moths from neighbouring orchards.

   From the time when moths are first caught in the pheromone trap, calculate the daily degree day. When, from the first continuous moth catch, the total of daily degree days reached 140 - or the number of moths trapped weekly is more than 2 moths per trap - an insecticide should be sprayed.

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B 4.3 Birds

Damage caused by birds in horticultural crops has been progressively increasing over the last 20 years in all producing areas. In walnut orchards in Victoria long-billed corellas, sulphur-crested cockatoos and galahs are causing the most damage, that was estimated in 1995 as over 50 tonnes per year. In addition birds also cause substantial losses by tearing and breaking young shoots and leaves.

Critical factors:

• **Species of bird, or birds**: This must be identified as there are significant variations in their feeding habits, general behaviour, response to changes in seasonal conditions, migratory nature, capacity to respond to perceived danger, etc.

• **Environment**: significant aspects of the area surrounding the plantation include: distance from native bush, or other plantations, suitable roosting and drinking areas, distance from neighbours, distance and time of ripening of other source of food.

• **Strategy**: once the characteristic behaviour of the potentially damaging species is identified, a plan has to be set up to prevent – or at least minimize – the damage in trees and nuts. Existing methods are based in the exclusion (netting), eradication (shooting, poisoning – where this is an available option), deterrence (gas canon, scarecrows, decoy models, reflective streamers, electronic noise makers) and provision of alternative food sources. Netting would not be effective for protecting old, developed trees, planted at low density, as the costs could be prohibitive, but in the new hedgerow type plantations, netting could be worth considering.

With eradication and deterrence, effectiveness depends on careful, daily monitoring of the presence and behaviour of birds, particularly during the period before the “scout” birds discovered the plantation as a suitable source of food and are followed by the rest of their flock. At this stage application of methods of eradication (subject to regulations) and/or the use of one or more types of deterrents could be far more effective than if the use of protective measures are delayed until the visits of birds become a routine behaviour.

Beside a wide variety of sophisticated deterrents and bird-specific distress signals, it also became feasible to use radar signals, which activate the sound deterrent only in the presence of birds. There is also a wide variety of bird scaring devices, from conventional scare-crows, to glittering strips and helium-filled balloons, which are placed in the orchards, as overnight deterrents, at regularly altered, strategic sites. It was found that usually more than one type of deterrent will have to be installed.

Monitoring throughout the season will pinpoint weaknesses – such as the birds getting used to the instrument, or noise and become less frightened by it. Then the strategy will have to be reviewed and suitable changes in the pattern used (moving the source of sound, altering the direction of the speakers, or the intervals between repeating sounds, etc) could make the system more effective.