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ALL ABOUT ALMONDS

INTEGRATED DISEASE MANAGEMENT

MANAGING ALMOND RUST

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Introduction

Almond rust is a wet weather fungal disease that if left unmanaged can defoliate trees by mid- to late-season reducing tree vigour, yields and bud viability for the next season. It grows best in warm humid conditions especially when there are extended periods of leaf wetness. Defence against rust requires preventative orchard sprays in spring and summer. Knowing the conditions that give rise to fungal diseases can assist with applying fungicides more precisely and effectively. Using specific information or data can help determine the risk of a disease event and can guide the need to apply fungicides against rust and potentially reduce the number of sprays needed for rust each season. A 'Rust Reckoner' and a web-based tool GrowCare® help to identify the conditions that favour rust infection and indicate when sprays are needed and when they are not.

The Disease

Rust is most obvious on leaves when rusty-brown powdery pustules develop on the undersides of small yellow leaf spots. The disease is sporadic in most regions of Australia because it is driven by warmth and moisture and only at irregular times and seasons are the conditions sufficiently warm and wet enough for long enough for the disease to be significant.

Crops infected

Commonly called 'prune rust', the disease in almonds is more correctly known as 'almond rust' or more simply, 'rust'. This is because the form of the rust fungus (Tranzschelia discolor f. sp. dulcis) that causes the disease, infects almonds but not plums. Conversely, the form of the fungus that infects plums or prunes will not 'cross-infect' almonds. Interestingly, the two forms (sub-species) of the rust fungus spread under similar conditions.

Similarly, many different species of rust occur on a wide range of plants including apricot, wheat, legumes, weeds and flowers. Rust spores from these plants do not spread to infect almonds.

Symptoms

On leaves

Rust first appears as many small (1-2 mm) angular, pale-bright yellow spots (lesions) on the upper surfaces of infected leaves (Figures 1a, 1b & 2a). These spots are usually limited in size and shape by the finest veinlets and are often grouped in small irregular clusters of three or more spots. With age, the spots often turn a golden yellow.

After the leaf spots appear, the lower surface of the spot breaks open forming a powdery pustule through which the orange-red spores of the rust fungus (uredospores) erupt. In favourable conditions, each pustule produces yellow orange to rusty brown, rounded tufts of these spores (Figures 1c & 2b). If touched, the spore masses readily leave a rusty brown deposit on your finger. This is diagnostic for rust disease.

As the leaf spots age, they turn golden yellow and then brown as the affected tissue within the spot dies. As symptoms progress on affected leaves, the tissue between the leaf spots turns yellow more quickly than the initial infection sites (Figures 3a, 3b). This is because the disease disrupts normal leaf function and causes the green chlorophyll activity to decline so that, eventually, a severely diseased leaf may appear yellow with small scattered green spots across the surface at each of the initial rust infection sites. This is characteristic of rust on severely diseased foliage late in the season.

Old pustules particularly in the autumn may turn black when a different type of spore, the winter or black rust spores (teleutospores) are produced. These appear to play no role in almond rust in Australia.

Severely affected leaves fall from diseased sectors of trees. If infection is severe, patches of defoliated trees will appear in the orchard.

Figure 1a.

Figure 1b.

Figure 1c. .

Typical angular, yellow lesions (spots) of the rust fungus on the upper surface of almond leaves (1a, 1b) and the characteristic raised, orange-brown rusty pustules beneath each spot (1c – same leaf as 1b).

On shoots

The disease only affects shoots when its severity on leaves is high. Rust on shoots appears as dark brown spots from which the characteristic rusty-brown pustules emerge in warm humid weather.

Diagnosis

Do not confuse rust spots with similar symptoms caused by other factors. Some symptoms will show yellow spots that also have a tiny dark centre. These may be the result of herbicide drift and damage, for example, caused by the knock-down herbicide, paraquat. The fungal disease shot hole also causes similar spots, but these have tan centres and develop a reddish-brown margin (halo). Sometimes, tiny dark brown spores (sporodochia) of that fungus develop in the centre of these spots which later die and fall out, leaving a 'shot holed' appearance.

To distinguish herbicide damage from shot hole look for spots that cross the finest veinlets. Also, a droplet of herbicide sometimes makes contact with the leaf in sufficient concentration to burn a little black spot in the centre of the yellow spot. In contrast, the shot hole fungus causes spots usually delimited by the finest veinlets. Herbicide damage will appear a few days after an application nearby or from distant drift event, whereas like rust disease, the spots from shot hole will appear more than 10 days after favourable wet conditions. But it is only rust that produces the rusty brown spore tufts in pustules on the undersides of the leaf spots.

Varietal Susceptibility

Most of the commonly grown almond varieties are susceptible to rust. A few varieties, when infected, show limited symptoms on upper leaf surfaces displaying only a few leaf spots before many rust pustules appear on the under surface of leaves. To the contrary, some varieties produce the yellow leaf spots but few pustules on the under surface.

Figure 2a

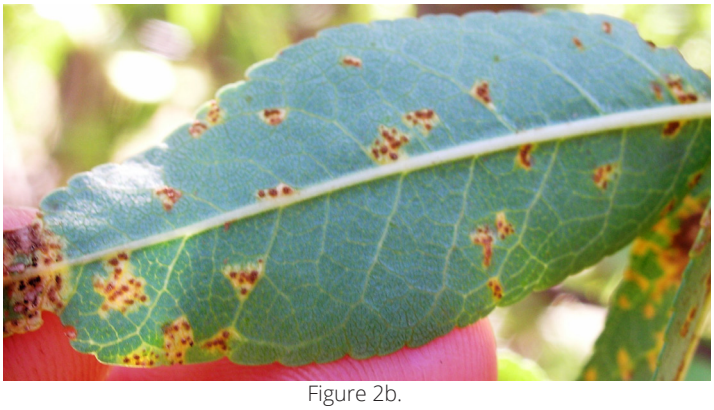

Figure 2b.

Figure 2a: To monitor for almond rust, look for the typical yellow lesions (spots) of the rust fungus on upper leaf surface of almonds. Confirm their identity by turning the leaf over to find the characteristic raised, rusty pustules on undersides (Figure 2b).

Figure 3a

Figure 3b

Figures 3: Progression in chlorosis (yellowing) of leaves severely affected by rust. The disease disrupts chlorophyll function (which relies on green tissue to produce food for the developing crop). Affected leaves turn yellow (3a) with scattered green speckling (3b) indicating where the rust infection had occurred. Severely diseased leaves fall prematurely – this can defoliate trees in patches or across an orchard.

Disease Cycle

Over-wintering

In Australia, rust begins from inoculum (urediniospores) on leaves that were infected last season but which remain over-winter attached in trees (Figures 3a, 3b). The disease is rarely triggered by inoculum from fallen leaves.

First infection

Rust can be called a 'green disease' in that it only infects green tissue. As a result, on unsprayed foliage, infection can begin if favourable conditions, particularly surface moisture on leaves, occur anytime from when leaves first emerge (Figure 4a - 4d). Spores from leaves infected last season spread in the wind and rain to infect nearby foliage.

Incubation

Once infection has occurred, a period of incubation follows. This is the time between infection and when symptoms first appear. It often extends over several days (see later) after which the small yellow rust spots will appear wherever infection occurred in the foliage.

Spread

The rust pustules beneath these spots produce more spores and if fungicide sprays have not adequately protected the foliage, the disease will spread, particularly on young almond foliage. After a second incubation period, many more spots will appear.

The disease cycle will continue as long as favourable weather occurs and the foliage remains unprotected. As said, the youngest foliage is very susceptible but, when leaves mature, they develop a degree of age-related (ontogenic) resistance, though they never become fully resistant.

Usually, only a few spots (with pustules beneath) will show after the first infection event for the season. Perhaps initially 5-50 pustules/leaf will develop in a cluster of foliage 20-50cm in diameter around the initial source of inoculum. These spots may pass un-noticed. Subsequent infections, especially in early-mid season, can produce many hundreds of leaf spots, often from 15-500 pustules/leaf within a zone 0.5–1.5m in diameter. In this way, if favourable conditions persist and adequate controls are not applied, rust spore numbers initially build-up slowly but then may explode, infecting several branches in one sector of a tree and/or often spreading rapidly throughout an unsprayed block of a susceptible variety in the orchard.

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Figure 4a.

Figure 4b.

Figure 4c.

Figure 4d.

Figure 4: Important stages in the growth cycle of almonds. The season begins as the buds crack open (green bud) (4a). Flowering (full bloom) (4b) is a critical time because young shoot growth soon develops (4c & 4d). In favourable conditions, this begins the rust season on the young susceptible leaf tissue. As the foliage matures, the leaves develop a level of tolerance to rust.

Crop Loss

In wet seasons, a series of favourable weather events can trigger a number of infection periods. In unprotected orchards, this will lead to severe disease which can defoliate trees by mid- to late-season. The result: significant crop loss this season and reduced tree vigour and bud viability in the next.

Favourable Conditions

Rust spreads in warm humid conditions especially when the foliage is more susceptible in early spring and summer. The spores of the rust fungus are very durable and survive long periods of dryness, but they need free-water (wet foliage) and adequate temperature to germinate, grow and cause infection.

Infection

The main factors required for infection are rainfall (or precipitation) to wet the foliage for sufficient length of time while there is adequate warmth for the fungus to develop and grow.

Spores of the rust fungus germinate at temperatures from 5 to 30°C but grow best at optimal temperatures of 15 to 24°C

Incubation period

Temperature is the main factor that governs the speed with which the yellow spots appear once infection has occurred, that is, temperature regulates the length of the incubation period. Preliminary evidence suggests that in cooler conditions between 10 to 15°C, the incubation period is about 20 to 22 days whereas in warmer conditions around 20 to 25°C, spots will appear from around 13 to 19 days after infection in warmer conditions around 20 to 25°C, spots will appear from around 13 to 19 days after infection.

Spread

The main factors that control the rate and extent of the spread of rust, that is, the speed and severity of the epidemic, are the initial number of spores (overwintering inoculum), the timing of rain events and the favourability of temperature and the duration of leaf wetness in the prevailing conditions. The fewer the number of spores, the less the risk of rust infection and spread in a severity of concern.

Rust Management

Spores of the rust fungus cannot infect unless there is water on the leaf or shoot surface. The cultivation of almonds in semi-arid environments, as occurs in most almond regions of Australia, provides minimum risk from rust infection. Spray schedules for other foliage diseases of almond, including shot hole, blossom blight and hull rot may also help suppress rust disease in the orchard.

For a given climatic region and for a specific variety cultivated, the main direct means of controlling rust involve reducing inoculum carry-over from one season to the next, and the use of well-designed spray programs.

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Over-wintering inoculum

Good disease control early in the previous season results in fewer infected leaves hanging on the tree over winter (Figure 5) and, as a result, less risk of disease if favourable weather prevails next spring. In autumn, consider cultural practices that lead to complete leaf fall (Figure 6).

The Three T's of good spray practice

Type

Infection-based. Prior to spraying, select the type of fungicide best suited to the timing of disease events. There are two categories of fungicide:

1. Pre-infection (protectant) products

Pre-infection fungicides are surface acting. They are not absorbed into sprayed foliage but they protect the sprayed foliage from infection. Because these fungicides do not move to unsprayed or new leaf and shoot growth, apply these as close as possible before an infection event.

For information on available pre-infection fungicides consult the ABA or your local chemical supplier.

2. Post-infection (curative) products

Post-infection fungicides are often known as 'trans laminar' (across leaf) products. This means that they are absorbed by the sprayed foliage and move within and across a sprayed surface in sufficient concentration to kill or at least, inhibit the rust fungus developing inside sprayed and infected foliage after infection has begun. Being quickly absorbed these fungicides are soon 'rain-fast'. But, like the pre-infection fungicides, these products do not move in sufficient concentrations from sprayed foliage to control the fungus in unsprayed leaves and shoots.

Post-infection products have capacity to kickback, that is provide some control of the disease if they are applied within 1-2 days after an infection event.

However, because 'prevention is better than cure' and because the post-infection products also have pre-infection activity against rust, it is generally best to apply them as soon as possible before infection, or if needed, as close possible after an infection event.

For information on available post-infection fungicides consult the ABA or your local chemical supplier.

Figure 6: A preferred view in late winter. These trees have completely defoliated overwinter, carrying no leaves infected the previous season and so bringing no inoculum to infect the new foliage about to develop.

Timing

Seasonal. It is critical to ensure good control of rust in early- to mid-season. This is when the foliage is most susceptible to rust and when the leaves are most needed as food factories to supply nutrients to the developing fruit crop.

But to ensure good control is achieved in early-season, it is critical to prevent the build-up of spores (inoculum) in the orchard. This is best done by preventing successive cycles of infection events especially in rain events in spring. From little things (that is, a few spores in early spring) big things grow (that is, lots of leaf canopy infected). It is best to time sprays to prevent the initial load of spores from multiplying.

Guides to spray timing

1. The 'Rust Reckoner'

As a simple guide to the timing of infection events, use the Rust Reckoner in Table 1. In three steps you can link the prevailing orchard temperature to the estimated length of time the foliage remains wet. This indicates if rust spores have caused infection.

Figure 5a

Figure 5b

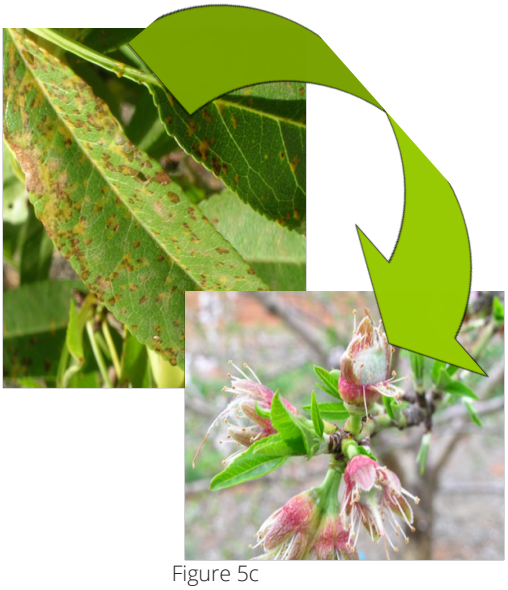

Figure 5c

Figure 5: Rust disease overwinters on leaves that were infected last season and remain on the trees (5a). In spring, the sporulating pustules on the undersides of these leaves are in close proximity to the developing foliage (5b). The disease easily infects new leaves if favourable conditions occur (5c).

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The Rust Reckoner provides a guide in answering:

- Did a rain event favour infection by rust? and, if so,
- When was the infection event? and What was the time interval between the application of the previous spray and the timing of that infection event?

This allows you to determine for each sprayed orchard-block:

- Whether a previous spray application was sufficiently timed prior to the infection event to have given effective cover to the existing foliage; and in consequence,
- Which patches were protected by your most recent spray and which were not; and, if not,
- Is a post-infection spray with a few days kick-back activity, needed as soon as possible after the event?

If it is too late for fungicide controls to stop the current infection event, a pre-infection spray may be needed as close as possible before the next forecast conditions that favour rust.

By recording the date of possible infection events during early to mid-season, you can accumulate an indication of the number and severity of rust events in the season to-date. This can guide you in determining if there is need to continue spraying.

In drier seasons in smaller orchards (that is, orchards able to be sprayed in quick time if needed), if there has been little accumulation of inoculum from repeat infection events (that is, seasonal disease risk is low), then further sprays may not be needed.

Figure 7: The Model T MetStation™, is both an automatic weather station (AWS) and a disease predictor for almond rust. The solar cell powers a mobile phone attachment allowing easy access to the data from a remote location.

This AWS and similar units collect weather data including temperature, rainfall, relative humidity and leaf wetness at 10 minute intervals. This information allows assessment of when infection by the almond rust fungus occurs. As a result, calculations can be made of the best times to spray for rust to provide the most effective and efficient control of the disease.

2. Web-based monitoring of infection events

The Rust Reckoner can assist you determine optimum timing of sprays for rust and identify times when sprays are not needed.

A web-based tool can assist in this aim with greater detail, ease and precision. Called GrowCare®, the system automatically assesses the suitability of the prevailing conditions for infection and can advise you of this via a text message or email.

Table 1. Use this Rust Reckoner as a guide to the conditions required for infection by almond rust in your orchard.

Temperature (Average °C)	Leaf wetness (Hours)	Temperature (Average °C)
15-24	6	
14	8	
13	10	25
12	12	
11	15	26
10	18	
9	20	27
8	23	
7	24	28

Three steps allow you to estimate the duration of leaf wetness for rust infection in your orchard:

1. First: check the prevailing temperature in your orchard.

2. Second: locate that temperature listed in either the left- or the right-hand column above.

3. Third: read the corresponding figure in the central column. This is an estimate of the number of hours that the leaves need to be wet for infection at that temperature.

Note: This Rust Reckoner is to be used as a guide only. It was derived from data in a prototype infection model for almond rust (Magarey and Western, unpublished data - as reported in Magarey, Wicks and Learhinan, 2009).

To achieve this, the GrowCare® system requires access to data from an automatic (electronic) weather station (AWS) that samples and records canopy conditions every 10 minutes (Figures 7 and 8). The AWS measure temperature, rainfall, relative humidity, and leaf wetness (a measure of how wet the foliage is) in the orchard canopy. These data are regularly relayed to the rust infection model within GrowCare ® which calculates the risk of infection by the rust fungus.

This tool processes orchard-based weather data to provide you with an assessment of the risk of infection by rust in the vicinity of the AWS that you elect to access. For a review of this website and/or to subscribe, go to www.growcare.com.au.

Note: Given the large size of almond orchards in many Australian production regions, the ratio of the number of spray machines to area of orchard to be sprayed, may currently limit the flexibility to apply sprays at optimum timing. This has relevance in many orchards that comprise a mixture of varieties each at different stages of foliage development and with differing susceptibilities to rust.

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Technique

Effective spray application technique requires careful attention:

- Choose spray machinery that provides good fungicide coverage of the trees in your orchard adjusted for increased canopy size and density both in early- and in later-season,
- Where needed, consider adjusting or modifying orchard design and tree structure to keep the canopy as low and as open as possible while maintaining optimum crop fruitfulness.
- Configure the spray machine according to the structure of trees and their shape and current size. Turn appropriate nozzles on or off to ensure the target foliage receives an effective spray cover, or alternatively, if using a multi-head machine, adjust the spray heads for maximum spray coverage.
- Calibrate spray machine and tractor speeds to deliver a volume of liquid adjusted to the target size of the foliage as it expands during a season.
- Select of an appropriate rate of product to deliver the correct dose of fungicide to the current target for optimum control.

Comment

Regular schedules of fungicide sprays have been mostly effective in protecting the foliage from the relatively few infection events that usually occur across Australian orchards. However, there is scope to use the Three T's to design better spray schedules with optimised use of fungicides and pesticides.

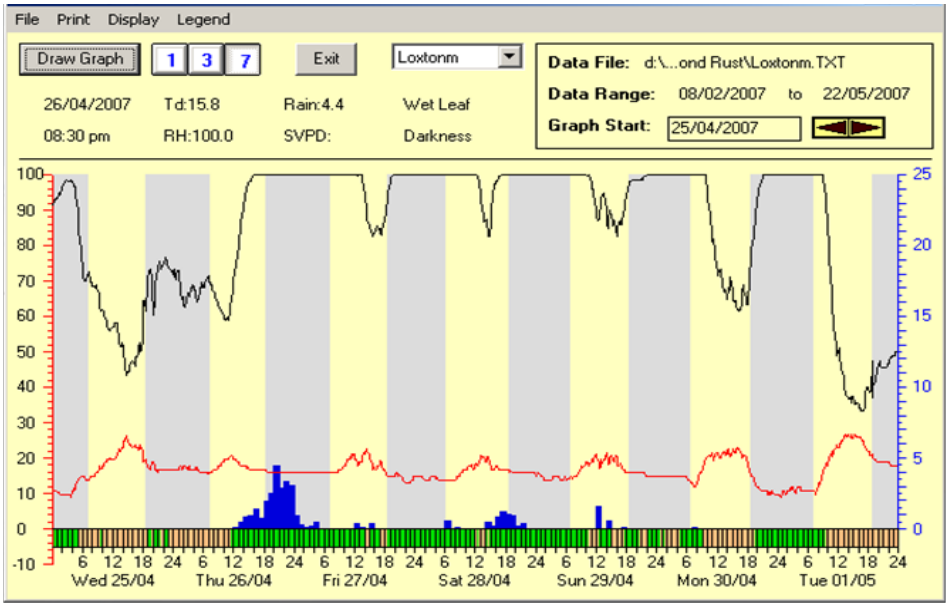

Figure 8: Graph of the data produced by the Model T MetStation™ (as above). Data are for the period 25th April to 1st May 2007. Rainfall (blue bars) began at midday (buff background) 26th April and continued overnight (gray background), bringing 33.4 mm over a 75 hour period of more or less continuous leaf wetness (green bar) whilst temperatures (red line) remained above 13^{0}C and relative humidity (RH) (black line) above 85%. These conditions triggered an infection by the almond rust fungus.

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