Growing oats in Western Australia for hay and grain

Raj Malik
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Growing oats in Western Australia for hay and grain
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Raj Malik, Blakely Paynter, Cindy Webster and Amelia McLarty
Department of Agriculture and Food, Western Australia
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Acronyms

ADF      Acid detergent fibre
ARGT    Annual ryegrass toxicity
ATP     adenosine triphosphate
BYDV   Barley yellow dwarf virus
CCN     Cereal cyst nematode
CP      Crude protein
DM      Dry matter
DMD     Dry matter digestibility
DTPA   diethylene triamine penta acetic acid
estME   Estimated metabolisable energy
EPR     End point royalty

IVD     in-vitro digestibility
MRL    Maximum residue limit
NDF    Neutral detergent fibre
RLN    Root lesion nematode
SARDI  South Australian Research and Development Institute
WSC    Water soluble carbohydrates

(1)    Plant Breeders Rights (PBR) protected variety
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Important tips for producing quality hay

- **Export hay** – Talk to your local hay processor before sowing oats for export hay. Hay processors have different requirements which will affect how you manage your crop. Your processor can advise you about their requirements for the production of export hay.

- **ARGT management** – Look to implement an annual ryegrass toxicity (ARGT) management plan through the introduction of the twist fungus or Safeguard ryegrass (Farmnote 417/2010). There is nil tolerance of ARGT for export and with export hay becoming a prescribed product, testing for ARGT will become compulsory.

- **Soil test** – As hay crops remove substantial amounts of nutrients, it is important to soil test paddocks, particularly those where hay is regularly grown.

- **Seeding rate** – Target 240 to 320 plants/m$^2$ (110 to 150 kg/ha depending on grain size). Higher is not always better as it can lead to reduced stem thickness in inherently narrow stemmed varieties like Wintaroo. Higher seeding rates do offer better weed competition and generally lead to increased hay yield.

- **Paddock preparation** – Roll paddocks after seeding but before the start of tillering (reduces contamination).

- **Potassium fertiliser** – Applying potash can improve both hay yields and hay quality. Potassium can improve quality by decreasing stem fibre (ADF and NDF) levels and in situations where inadequate nitrogen fertiliser has been applied, increase water soluble carbohydrates. Varieties appear to react similarly to potassium application.

- **Nitrogen fertiliser** – Do not apply excessive levels of nitrogen as it may decrease hay quality by increasing stem fibre levels (ADF and NDF) and decreasing water soluble carbohydrates. Varieties may differ in their response to applied nitrogen.

- **Row spacing** – Maximum row spacing for oaten hay is 180 mm. This assists with keeping the hay swath off ground.

- **Cutting date risk** – Sowing date and variety maturity can be used to minimise the risk of all your hay being on the ground at the same time. Spreading the sowing date of a variety over a week or so; or sowing two varieties of differing maturity can reduce the risk of weather damage due to adverse weather conditions after cutting.
- Disease – In high disease risk areas where a susceptible variety has been sown, early label applications of a registered fungicide may lower the impact of disease infection on the physical appearance of hay for export.

- With holding periods – Only apply registered herbicides and fungicides in accordance with the label registrations as some export markets such as Japan have recently introduced Maximum Residue Limits (MRL) in feed products. Do not apply a herbicide or fungicide within a withholding period before cutting.

- Contractors – Talk in advance to your contractor about the suggested cutting date so that machinery is available at the crucial cutting time.

- Cutting stage – Cut hay at the watery ripe stage (Z71). This usually occurs in late September to early October with a May planted crop. A later cut gives a yield advantage but quality drops. Quality may be better when cutting early but there are yield penalties. Cutting at the watery ripe stage is the best compromise between high yield and high quality. Varieties with good colour like Wintaroo (l) need to be monitored carefully, to make sure that they are cut at the right stage.

- Cutting height – Cut hay at least 15 cm high. If stems are thick, cut a bit higher to reduce fibre content.

- Super conditioners – The use of super conditioners can reduce the risk of weather damage by reducing the interval between cutting and baling from 10 to 14 days down to 4 or 5 days. In good drying conditions however, super conditioning can result in hay becoming too dry and make it difficult to form a good bale.

- Baling – Bale when moisture has dropped to between 12 and 14 per cent.

Important tips for producing quality oat grain

- End use - Decide on whether you are growing for milling or feed.
- Receival standards - Make yourself aware of the oat receival standards and quality segregations. Full details of oat receival standards can be obtained from CBH. (www.cbh.com.au). The oats are segregated into two grades - Oat 1 (formerly milling) and Oat 2 (formerly feed) - to reflect the quality and the markets into which these segregations are sold.
- Varieties - Consider varieties which are suitable for the targeted end use and quality. Then compare the relative yields and/or gross margins of the varieties by end use and quality. Assess risk factors of specific varieties such as disease, lodging risk, shedding risk and quality issues. Check with buyers before selecting a variety for a particular market.
- Soil type - Oat grain crops grow more favourably in medium textured soils with good water holding capacity and medium to high fertility levels. Also, avoid low lying paddocks to avoid waterlogging or severe frost incidents.
- Seed size - Always sow plump seed - certified or otherwise. Plump seed contains more food resources that promote the establishment of strong healthy seedlings.
- Date of seeding - Sowing time should be matched to the maturity of chosen variety to ensure the plant flowers at its optimum time and reaches its maximum yield potential. Crops sown too early or too late may not achieve optimum growth resulting in lower yield and quality. Long season varieties should be sown first (late April to mid-May) and short-mid season varieties later (late May to mid June).
- Seed dressing - Always treat seed with a suitable fungicide seed dressing when appropriate. Seed dressings provide protection against smuts particularly loose smut and bunt diseases.
- Disease - There are limited fungicide options for oats. For control of rusts (stem and leaf) apply a label rate of propiconazole or tebuconazole. For suppression of septoria apply a label rate of propiconazole. Always follow label recommendations.
- Seeding rate - Maintain a plant density of 240 plants/m² with a row spacing of 18cm. This combination promotes good ground cover. If weeds are a serious issue consider increasing plant density to help plants compete better with weeds. Higher plant densities also compensate for the lack of tillering experienced in waterlogged conditions.
• Seeding depth - Sow seed 3-6 cm deep (coleoptile length) using press wheels. The press wheels will compress the soil directly above the seed ensuring even seeding depth, and may also help overcome water repellent soils.

• Soil test - Soil testing is essential before applying fertilisers. For a healthy crop, both macro and micro nutrients are needed in adequate amounts. Pay special attention to soil test results if hay was grown previously in the same paddock because hay removes substantial amounts of nutrients particularly potassium from the soil.

• Fertiliser - Ensure phosphorus levels are adequate for good growth and to reduce the risk of screenings and to improve hectolitre weight and groat %. Nitrogen and potassium are complementary to each other in improving yield and quality and thus both are needed in adequate amounts to take full economic advantage.

• Weed control - Pre-seeding weed control is vital as in-crop weed control options are limited.

• Insects - In high risk aphid years (with a summer/autumn green bridge or in disease prone regions), anti-feeding insecticides (alpha-cypermethrin) should be applied at 3 and 7 weeks after emergence regardless of whether aphids can be seen on the plants.

• Harvest - To reduce shedding losses harvest the crop as soon as it ripens and has grain moisture, less than 12%.

• Storage - Store the oats in clean, dry water proof silos, the maximum moisture content at which oats can be safely stored is 12.5%.

• Insects in stored grain - Inspect stored grain for insects at least once a month to prevent any severe infestation. Information on the control of stored oat grain pests can be found on the DAFWA website www.agric.wa.gov.au and the GRDC stored grain website www.storedgrain.com.au
Introduction

*Raj Malik, Cindy Webster*

The oat industry in Western Australia has made phenomenal progress in recent years with the discovery of new markets, the release of several high yielding varieties and the development of agronomic guidelines through rigorous research programs. Oat production in Western Australia for the domestic and export market has significantly increased over the past few years. Oats are now regarded as one of the most profitable cropping enterprises. Oat production is mainly export orientated and thus has a substantial economic influence on the agricultural industry.

In Western Australia, oats are grown for grain, for both milling and feed, and for hay. As oats are versatile in their regeneration they also offer an opportunity for grazing before they are cut for hay or harvested for grain. Oats also play an integral role in farming systems due to their rotational benefits.

Export hay fits into most of the accepted cropping rotations and helps to reduce weed seed banks, overcomes herbicide resistance and provides a break from traditional chemical regimes in addition to giving growers an alternative cash crop. Cutting oats for hay effectively reduces the risk of ARGT as ryegrass plants (and other hosts) are removed from the paddock prior to toxin formation. Furthermore, oats have a greater tolerance to waterlogging and frost than other cereals.

West Australian oats are reputed to be of the highest quality in the world and they successfully meet the requirements for human and animal consumption. As international buyers, such as Japan, become increasingly focused on the quality of oats, it is important that West Australian growers continue to supply produce that meets premium standards and expectations.

Sound, agronomic management is essential to produce quality grain oats and oaten hay that meets the expectations of growers and buyers.

This bulletin provides the industry with a practical management guide to produce high quality and profitable oat crops for grain and hay. The bulletin highlights some important in and out of paddock issues and suggests some agronomic guidelines for successful oat production.
Paddock selection

Selecting the appropriate paddock is fundamental for producing high quality hay and oat grain crops. Consider selecting paddocks that:

- are not prone to long periods of waterlogging. Despite having a higher tolerance than other cereals, long periods of perched water within 30 cm of the soil surface can reduce potential yields by 60 per cent.
- have minimal weed burdens and are capable of a double knockdown before seeding.
- do not have a history of rhizoctonia bare patch, take-all, ryegrass and doublegee. There is a zero tolerance against ARGT in export hay.

Also avoid paddocks with the following characteristics:

- a history of leaf (foliar) disease in the previous oat crop. Try to break up the disease cycle with a suitable crop rotation as there are very limited fungicide options to control foliar diseases in oats.
- a low pH < 4.5 or high salinity and compaction
- covered with large stones, carcasses, tree branches, heavy crop residues and other foreign objects that may contaminate the hay and result in downgrading or rejection of export hay. Paddock preparation (that is, removing these contaminants) plays a major part of management.

The detrimental effect of herbicide residues from preceding crops must be considered in the decision to grow oats in rotations. Oat plants are sensitive to sulfonylurea (SUs), imidazolinone and triazine residues. Where residual herbicides have been used on prior crops during drier seasons, a test at sowing can confirm if the residues will harm the oat crop.

Soil characteristics

Oats grown for grain and oats grown for hay require slightly different soil characteristics for their optimal production.

Oats for grain should be sown in soils with medium to high soil fertility. In contrast, oats for hay should be sown in soils of moderate fertility only, in the range of 80 kg/ha and less of available nitrogen (N) in the top 60 cm at sowing. On highly fertile soils oaten hay crops produce greater biomass rather than quality hay. This can affect the dollar returns for the paddock because quality ultimately determines the final price.

To avoid lodging, hay crops should be sown in paddocks where the soil is expected to have low N mineralisation rates, from previous pasture legume stubbles and pulses.

Oaten grain crops grow more favorably in medium textured soils with greater water holding capacity.

All oat crops, irrespective of whether they are grown for grain or for hay, require deep well-drained soils with at least 0.5 m of suitable root zone.
Rotation

Canola is an ideal break crop for oats because it provides an excellent opportunity to reduce grass weeds and minimise foliar and root diseases for hay. One should be cautious if using residual herbicides for weed control in canola; stubble residue must be managed to avoid contamination.

After a good medic (Medicago) pasture stand or a high biomass pulse/low yielding pulse crop on heavy soils it is likely that the high soil nitrogen levels may increase the acid detergent fibre (ADF) and the neutral detergent fibre (NDF) contents and the likelihood of lodging in hay crops, especially in tall varieties. However, on lighter soils and or following a weaker pasture legume base or high yielding pulse crop, lodging will not be an issue with tall varieties. Conversely when growing oats for grain, high soil nitrogen will be more of an advantage as it will increase grain yield and any reduction if any in grain quality is not so much of an issue.

Frost risk management

Although oats are considered to be tolerant to frost, some damage can still occur in Western Australia. The most damaging stage for frost is after ear emergence. If anthers are damaged during ear emergence, sterility may result. The grain can become shrivelled if the frost event occurs during the milky ripe stage.

To minimise the chance of a crop being frosted, avoid high risk areas of paddocks, such as valley floors. Sow as late as possible in the range of optimum sowing dates so that the plant flowers in its optimum window but as late as possible.
Crop establishment

Raj Malik, Cindy Webster

Variety selection
The following factors should be considered before deciding which variety to sow:
- end use - milling, feed or hay
- yield - relative yield of milling, feed and hay varieties
- adaptation - suitability of the variety for a particular Agzone.

Other considerations when selecting varieties include maturity, disease resistance, lodging resistance and quality aspects.

In 2006 the milling and feed oat segregations were renamed ‘Oat 1’ and ‘Oat 2’ to better reflect the quality of oats and the markets into which these segregations are sold.

Oats for milling (Oat 1) are received on the basis of grain physical quality including hectolitre weight, free groats, screenings and moisture. Unlike other cereals there are no receival standards for protein and colour.

The receival requirement for Oat 1 grade are a minimum hectolitre weight of 51 kg/hL and screening levels (< 2.0 mm) less than 10 per cent. The receival requirement for Oat 2 is a minimum hectolitre weight of 49 kg/hL.

There is no limit on screenings for Oat 2 deliveries. The moisture level should be less than 12 per cent for both categories. Full details of receival specifications can be obtained from the CBH Group (www.cbh.com.au)

The export hay market is very much a niche market that is driven by high quality and consistent supply. Over the past few years the major buyers of Australian hay have been the Asian markets, particularly Japan, South Korea and Taiwan.

Current varieties available for Western Australian growers are listed in Table 1. Depending on market demand a premium may be offered for the Oat 2 variety Wandering. Consult with your preferred acquirer to see if a premium will be offered before planting this variety.

End users often have a preference for a particular variety and growers are advised to talk to their preferred grain or hay acquirer as to their variety preferences before sowing an oat crop. Sometimes different end uses also require specific levels of management and agronomic inputs.

Table 1. Important milling, feed and hay oat varieties available for Western Australian growers

<table>
<thead>
<tr>
<th>Oat 1 (milling)</th>
<th>Oat 2 (feed)</th>
<th>Hay</th>
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<tbody>
<tr>
<td>Carrolup</td>
<td>Brusher (b)</td>
<td>Brusher (b)</td>
</tr>
<tr>
<td>Coomaloo</td>
<td>Dalyup</td>
<td>Carrolup</td>
</tr>
<tr>
<td>Hotham</td>
<td>Euro</td>
<td>Kangaroo (b)</td>
</tr>
<tr>
<td>Kojonup (b)</td>
<td>Kalgan</td>
<td>Marloo</td>
</tr>
<tr>
<td>Mitika (b)</td>
<td>Mitika (b)</td>
<td>Mulgara (b)</td>
</tr>
<tr>
<td>Mortlock</td>
<td>Murray</td>
<td>Swan</td>
</tr>
<tr>
<td>Pallinup (b)</td>
<td>Needilup</td>
<td>Tungoo (b)</td>
</tr>
<tr>
<td>Yaillara (b)</td>
<td>Potoroo</td>
<td>Vasse</td>
</tr>
<tr>
<td></td>
<td>Quoll (b)</td>
<td>Wandering (b)</td>
</tr>
<tr>
<td></td>
<td>Swan</td>
<td>Winjardie</td>
</tr>
<tr>
<td></td>
<td>Toodyay</td>
<td>Wintaroo (b)</td>
</tr>
<tr>
<td></td>
<td>Wandering (b)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Winjardie</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wintaroo (b)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yilgarn</td>
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</tbody>
</table>

Sowing
Sowing plump seed (certified seed or seed from a paddock with a good fertiliser history) treated with a seed dressing at the right depth and right spacing is an important first step towards achieving vigorous and healthy seedlings.
Sowing depth

The recommended depth for oat varieties is 3 to 6 cm. This depth is sufficient for the oat seedlings to emerge through elongation of the mesocotyl and the coleoptile through the soil. In contrast, wheat and barley seedlings emerge by coleoptile extension only consequently oats can usually be sown deeper than wheat and barley. In drier seasons this trait allows oats to be sown relatively deep in an attempt to pursue moisture sufficient for good germination.

Coleoptile lengths do vary for different varieties as shown for selected varieties in Table 2. Varieties with the longer coleoptile length (such as Winjardie) can generally be sown slightly deeper than shorter coleoptile length varieties (such as Carrolup).

Using press wheels during sowing will compress the soil directly above the seed for even distribution during seeding, and will sow seed more efficiently in water repellent soils. Standard tined seeders will spread seed through a band of 2 to 3 cm with the occasional seed being left on the soil surface.

Row spacing

Using press wheels during sowing will compress the soil directly above the seed for even distribution during seeding, and will sow seed more efficiently in water repellent soils. Standard tined seeders will spread seed through a band of 2 to 3 cm with the occasional seed being left on the soil surface.

Plant density

The plant density generally recommended for hay and grain is 240 plants/m². However, for hay the plant population can be increased to 320 plants/m² to help plants compete better with weeds and to reduce stem thickness, which is desirable in quality export hay. Oaten hay trials in Western Australia have shown that increasing the number of established plants increases hay yields in addition to reducing stem thickness.

Higher plant densities also compensate for the lack of tillering experienced in waterlogged conditions.

If moderate to high grass weed densities are likely, increase the target plant densities to approximately 400 plants/m². This will increase crop competitiveness against weeds. Research has shown that increasing the seeding rates from 240 to 400 plants/m² reduced weed biomass by 25 per cent without any effects on grain yield and grain quality.

Higher seeding rates should also be used in the following situations when:

• Seedling emergence and establishment are likely to be reduced.
• Plant tillering is expected to be low because of a variety or soil condition effects.
• Sowing is delayed.
• Good rains are likely during the season.
• Soil fertility and moisture levels are high.
• A dry finish to the season is predicted.
• There is a high possibility of an insect infestation that will cause seed mortality.

Where lodging could be a problem, target densities should be reduced marginally. This encourages the crop to grow thicker stems but not to the extent that it might reduce hay quality with overly-thick stems.

Table 2. Coleoptile length of selected oat varieties after germinating in the dark for 12 days at 20°C

<table>
<thead>
<tr>
<th>Variety</th>
<th>Coleoptile size</th>
<th>Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrolup</td>
<td>Medium</td>
<td>60 to 69</td>
</tr>
<tr>
<td>Dalyup</td>
<td>Long</td>
<td>70 to 89</td>
</tr>
<tr>
<td>Mortlock</td>
<td>Long</td>
<td>70 to 89</td>
</tr>
<tr>
<td>Winjardie</td>
<td>Very long</td>
<td>&gt; 90</td>
</tr>
</tbody>
</table>
In crops grown on stored soil moisture under rain fed conditions typical of the state, the population should not be so high that it depletes most of the moisture before the crop matures and not so low that it leaves moisture unutilised.

Oats for hay can also be sown in a cross fashion (in two directions) to accommodate more plants which aids in reducing stem thickness and weed population.

**Calculating / estimating seeding rates**

The number of plants established from a given weight of seeds depends on the size of the seeds and the percentage of those seeds that are viable and grow into established plants. Depth of sowing, disease, soil crusting, moisture and other stresses in the seedbed will affect the number of plants establishing.

Oat varieties differ in their grain weight. The average grain weight of some varieties are shown in Table 3. To estimate seed weight for those not listed, count and weigh 1000 grains of the graded seed sample. The seed rate can then be calculated by using the following formula opposite:

For example, for the desired plant population of 240 plants/m² with an average grain weight of 40 mg and an expected establishment of 80 per cent, the required seeding rate is \((240 \times 40)/80 = 120\) kg / ha.

More examples of seed rates calculated on the basis of target plant populations, grain weight and an expected 80 per cent seed germination percentage are shown in Table 3.

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**Table 3. Amount of seed required (kg/ha) to achieve a desired plant population for some oat varieties (80 per cent establishment is assumed)**

<table>
<thead>
<tr>
<th>Average grain weight (mg)</th>
<th>Target plant populations (plants/m²)</th>
<th>Seeding rate (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>160  240  320</td>
<td></td>
</tr>
<tr>
<td>33 (e.g. Echidna, Vasse)</td>
<td>66   99   132</td>
<td></td>
</tr>
<tr>
<td>35 (e.g. Possum (h))</td>
<td>70   105  140</td>
<td></td>
</tr>
<tr>
<td>37 (e.g. Carrolup, Kojonup (h), Wandering (h))</td>
<td>74   111  148</td>
<td></td>
</tr>
<tr>
<td>39 (e.g. Dalyup, Swan, Winjardie)</td>
<td>78   117  156</td>
<td></td>
</tr>
</tbody>
</table>

---

**Estimating target plant population**

Estimating seedling numbers is a way to determine how well the crop has established. Count the number of plants four to six weeks after seeding at a minimum of 10 randomly selected sites representing the whole paddock. Place a 1 m long ruler between two rows and count the number of plants along both sides of the ruler. Use the formula opposite to estimate the plant population in one square metre area.

For example, if 1000 plants are counted from 10 sites, and row spacing is 18 cm, the number of plants per square metre is: \(1000 / (10 \times (2 \times 0.18)) = 278\).

**Sowing time**

Opening rains or seasonal break and the maturity time of the chosen variety dictate when to sow oats. Sowing time should be matched to the maturity of the chosen variety to ensure that the plant flowers at its optimum time and reaches its maximum yield potential. Crops that flower too early may not achieve maximum growth resulting in low yields and the crop is exposed to the risk of frost damage and weather staining of the grain. Crops that flower too late may have lower yields and higher screenings due to grain filling occurring at higher than optimum temperatures and limited soil moisture.
The varieties Needilup, Possum, Swan and Winjardie are more daylight sensitive than other oat varieties. This means that these varieties may flower at a different time relative to other varieties in the same maturity group when sown in early May or late June. For example, Winjardie sown in late April may reach the watery ripe stage 14 days later than Carrolup. However, when sown in May Winjardie is only 7 days later than Carrolup and 3 days later than Carrolup when sown in late June reaching the watery ripe stage.

It is important to know the relative maturity of hay varieties for hay production, particularly if the hay enterprise is particularly large. A number of varieties with differing maturities can be grown which will then increase the optimum cutting/swathing window for quality and production and subsequent baling. It also reduces the risk of weather damage to the entire hay enterprise.

For most areas in Western Australia, the ideal time to flower (flowering window) is September. For areas around and north of the Great Eastern Highway the flowering window is the whole of September. For the Great Southern the flowering window ranges from mid-September to early October.

Long season varieties (e.g. Vasse) should be sown first from late April to mid-May. Short to medium season varieties (e.g. Hotham and Carrolup) should be sown from late May to mid-June in late June. Table 4 shows the maturity groups of some grain and hay oat varieties. The maturity group ranking is based on the flowering date of oats when sown in late May and early June.

### Table 4. Maturity groups for some oat grain and hay varieties

<table>
<thead>
<tr>
<th>Maturity group</th>
<th>Grain Varieties</th>
<th>Hay Varieties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early</td>
<td>Hotham, Pallinup</td>
<td>–</td>
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<tr>
<td>Early – Medium</td>
<td>Carrolup, Coomallo, Dalyup, Kojonup, Mitika, Quoll, Wandering, Carrolup, Yallara</td>
<td>Carrolup, Massif, Swan, Wanderg, Wintaroo</td>
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<tr>
<td>Medium</td>
<td>–</td>
<td>Kangaroo, Winjardie</td>
</tr>
<tr>
<td>Medium – Late</td>
<td>Needilup</td>
<td>Vasse</td>
</tr>
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</table>

As hay needs to be relatively clean and weed-free, sowing time may also be dictated by the need to wait for weeds and volunteers to germinate to ensure a good knockdown before sowing.

Research in Western Australia has shown that delayed sowing causes reductions in yields of up to 17 kg/ha/day (Figure 1) and affects the quality of the grain (Figure 2).

![Figure 1. Interaction of time of sowing and site_year on average oat grain yield. (LSD <0.05; TOS = 0.45; site_year = 0.18; TOS x site_year = 0.35)](image)

Figure 2 represents the effect of seeding time on quality of grain oats. The values are the difference between early and late seeding treatments giving a positive (+) if early sowing value is higher quality or negative (-) values if late sowing value is higher quality. It is apparent that the grain physical quality declined when sowing was delayed. Average grain weight (1000 grain weight) decreased in all but one trial when oats were seeded late. Hectolitre weight decreased also and screening (%<2.00 mm) levels increased in 14 out of
18 trials. Influence on groat content was not very clear whereas protein content increased while oil content declined with delayed sowing in majority of trials. Also grain colour was reduced but grain brightness improved in most of the trials due to late sowing.

**Early sowing**
Sowing as early as possible with a later maturing variety can result in the following for grain:
- The crop will have the opportunity to achieve the highest possible yield (Figure 1).
- The grain protein content will be lower (a one-month delay in sowing can increase protein by 1 per cent) (Figure 2).

For hay:
- Foliar diseases will be more severe. So it is important to consider the more disease resistant varieties.
- In good growing conditions the crop will be taller and may lodge.
- Sowing early with an early maturing variety increases the risk of cut hay being exposed to rainfall.

**Late sowing**
Sowing late in the season with an early maturing variety may lead to the following for grain:
- The crop will be lower yielding but will have higher grain protein because it will flower and fill the grain later in spring when moisture is likely to be limiting and temperatures are higher.

For hay:
- Foliar diseases, lodging and shedding might be less severe.
- Hay quality may be reduced.
Oat has traditionally been considered a low input crop and has generally been grown on paddocks with lower soil fertility. The development of higher yielding grain and hay varieties combined with greater emphasis on grain and hay quality from both export and domestic markets means that nutrient management now has to be more carefully considered when growing oats.

The agricultural areas of Western Australia are dominated by sandy soils. They are characterised by low amounts of organic matter and a poor ability to retain water and nutrients. As with wheat and barley crops, oat crops grow poorly without the addition of nutrients. The major nutrients required for healthy growth are nitrogen (N), phosphorus (P), potassium (K) and sulphur (S); and the micro-nutrients required for healthy growth are copper (Cu), manganese (Mn), molybdenum (Mo) and zinc (Zn).

Oat crops, particularly oaten hay, remove significant quantities of all the major nutrients. It is, therefore, important for growers to use both soil testing and tissue testing to ensure that the crop nutrient status is adequate for plant growth. Application of nutrients is required to optimise production either on an annual basis for nutrients like N and P or less frequently for the micro-nutrients like Cu and Zn. Table 5 gives an estimate of the quantity of nutrients removed in one tonne of grain and straw. However, these values can vary markedly with soil type, season and management.

The continued loss of nutrients from paddocks without replacement becomes particularly important when the soils are already marginal or deficient in nutrients. The continued depletion of nutrients, particularly K from soil with adequate amounts will eventually reduce soil K supply and decrease the productivity and quality of produce. Removing nutrients from the soil may also reduce the pH of the soil. As the plant material is removed from the paddock, there is a net export of alkalinity which leaves behind residual hydrogen ions in the soil to maintain electrical balance. Over the time, as this process is repeated the soil becomes acidic. Farmnote 97/2001 (Falconer & Bowden 2001) provides further information on when exported nutrients should be replaced and the implications and cost for crop production when soil fertility falls below critical levels.

**Nitrogen**

**The importance of N management**

Nitrogen is largely responsible for setting up the yield potential of the crop. Nitrogen is required for tiller development and required by plants to create protein. The N for plant growth is supplied from both the soil and from N fertiliser application. Nitrogen is taken up by the oat plant when it is in an inorganic form (as either ammonium or nitrate). In the soil over 98 per cent of the N is in an organic form which cannot be taken up by the oat plant until it is mineralised. A large proportion of the oat plants requirement for N is
supplied by the soil. Where the available N supply from the soil is inadequate for optimum yield and quality, N fertiliser is required. Soil testing helps estimate the amount of N already available in the soil. Soil type, cropping history, yield potential and the season are important factors to consider in N management decisions.

The amount of N fertiliser required to grow a grain or oat hay can be estimated from fertiliser decision support programs. One such decision support tool is Select Your Nitrogen. It was developed by the Department of Agriculture and Food Western Australia. Select Your Nitrogen is a spreadsheet based decision support tool for quantifying N availability and crop response.

As a rule of thumb, N fertiliser at 40 to 80 kg N/ha has been found ideal for most growing conditions in WA. The amount of N required will be modified by seasonal conditions and the oat variety. As dwarf varieties like Kojonup and Wandering have a higher N requirement, it is suggested that the N application rate used be increased by about 20 per cent above that recommend for a non-dwarf variety like Carrolup. Plant emergence can be reduced if applying urea at more than 30 kg N/ha is drilled too close to the seed.

Oat hay and grain yield increases (response) to applied N depends on the soil moisture available during the season. In a dry season there is usually a poor crop response to applied N due to the reduced rate of mineralisation of granular N fertiliser and possible lack of soil available water. Depending on the crop yield potential, applying a foliar spray of N in drier years may be a better option than granular fertilisers. Poor finishes to the season also reduce crop yield irrespective of how much N is applied.

In wet seasons, leaching of N can occur, particularly in sandy soils. In leaching situations, the N requirement for oats can be delayed and/or split to reduce the N lost by leaching. To maximise hay quality, any late N should be applied between tillering (Z25) and stem elongation (Z31). Applying N too late (later than Z33) causes nitrites to accumulate in the plant dry matter reducing hay quality. For grain yield, profitable responses to N application have been found up to 10 weeks after sowing. There is generally little chance of a profitable yield increase to N fertiliser occurring if the N is applied later than 10 weeks after seeding.

Tables 6 and 7 provide examples of how N fertiliser can influence the yield and quality of oats when grown for grain (Table 6) and hay (Table 7). Data are presented from six experiments, three conducted in 2005 and three conducted in 2006.

Increasing N supply:
- may increase hay yield
- increases hay greenness
- increases stem fibre levels (ADF and NDF)
- decreases WSC
- may increase IVD and ME slightly
- may sometimes lead to high nitrate N levels. High nitrate levels are unacceptable in many hay markets
- interacts with variety for fibre and WSC. Research has suggested that quality of Kojonup hay is least sensitive and of Wandering is more sensitive to higher applications of N levels (Figure 3)
- method of N application is also important. Research has shown that it is important to split N, particularly for hay. Figure 4 provides an example of how 3 varieties responded differently to split N in 2 trials conducted at Katanning and Narrakine in 2007. Varieties may respond differently to split N. It’s evident that varieties Wintaroo and Wandering required all the N be applied early at seeding as opposed to Carrolup which required N to be evenly split between 6 weeks after seeding and at Z31. No variety responded to the entire N applied later at Z31. The data also suggested a late N may not have any detrimental effect on grain yield regardless of variety. Further research is required on methods of N application including Flexi N for oat varieties at a range of locations.
Table 6. Change in grain yield and grain quality as nitrogen supply is increased from 15 to 80 kg N/ha at six sites sown in 2005 and 2006

<table>
<thead>
<tr>
<th>N applied (kg N/ha)</th>
<th>Year</th>
<th>Rainfall (mm)</th>
<th>Site</th>
<th>Grain yield (t/ha)</th>
<th>Average grain wt (mg)</th>
<th>Hectolitre wt (kg/hl)</th>
<th>Screening (%&lt; 2 mm)</th>
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</table>

LSD (p=0.05) N Site year x N

Table 7. Change in hay yield and hay quality as nitrogen supply is increased from 15 to 80 kg N/ha at six sites sown in 2005 and 2006

<table>
<thead>
<tr>
<th>N applied (kg N/ha)</th>
<th>Year</th>
<th>Rainfall (mm)</th>
<th>Site</th>
<th>Hay yield (t/ha)</th>
<th>Leaf greenness (SPAD)</th>
<th>Crude protein (%)</th>
<th>ADF (%)</th>
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LSD (p=0.05) N Site year x N

Protein (%) Oil (%) Groat (%) Grain brightness (Minolta L)

Table 8. Change in hay yield and hay quality as nitrogen supply is increased from 15 to 80 kg N/ha at six sites sown in 2005 and 2006

<table>
<thead>
<tr>
<th>N applied (kg N/ha)</th>
<th>Year</th>
<th>Rainfall (mm)</th>
<th>Site</th>
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<td>4.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>236</td>
<td>Williams</td>
<td>3.8</td>
<td>5.2</td>
<td>3.2</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>303</td>
<td>Boyup Brook</td>
<td>3.8</td>
<td>5.2</td>
<td>3.2</td>
<td>4.1</td>
</tr>
</tbody>
</table>

LSD (p=0.05) N Site year x N

NDF (%) IVD (%) Est ME (% WSC (%) WSC (%)
Nitrogen interaction with seeding rates

The research has shown that the response of oat grain yields to seeding rate was independent of the N application rates (Figure 5). High seeding rates and high N fertiliser rates increased screenings but no other quality parameters (Figure 5).

For hay production, do not apply excessive levels of N as it may decrease hay quality by increasing stem fibre levels (ADF and NDF) and decreasing water soluble carbohydrates. Varieties may differ in their response to amount and of method of applied nitrogen.
Increasing the seeding rate will increase oat grain and hay yields irrespective of N fertiliser levels. Higher seeding rates will increase grain screenings and reduce leaf greenness in hay. However, higher N fertiliser rates will increase yields.

Hay yield response to seeding rate was independent of the level of applied N (Figure 6).

Leaf greenness was the only aspect of hay quality that decreased as seeding rate and N levels increased (Figure 6). At low levels of N there was a larger drop in upper canopy leaf greenness as the number of plants sown increased, compared greater amount of N applied. Stem thickness of oats decreased as seeding rate increased irrespective of N fertiliser (Figure 6).

**Nitrogen interaction with potassium**

Trials conducted at at Katanning, Meckering, Narrogin, Yerecoin, Brookton and Williams have shown that both N and K are important to optimize yield and quality of oat hay and grain. When soil tests K levels are low (Colwell K soil test of less than 80 mg/kg) the response of oat plants to fertiliser N can be affected by K deficiency. To optimise the response to fertiliser N, adequate K fertiliser has to be applied.

The results suggested that both oats hay and grain yields were governed mainly by applied N but required at least 70 kg K/ha to achieve their optimum levels (Figure 5). The hay yield increased by 1.7 t/ha by applying an extra 65 kg of N (from 15 to 80 kg N/ha) where no K was applied, whist at 70 kg applied K the corresponding hay yield increased by 2.1 t/ha. Highest hay yield was achieved with 80 kg N/ha and 100 kg K/ha. This means that N and K are required in adequate amounts to achieve maximum economic yield.

Whilst N and K interact to influence hay yield, they do no interact to influence hay quality. On K deficient soils, increasing K (regardless of N supply) reduces NDF and crude protein and increases WSC of the hay.

Grain yield increased as combined N and K fertiliser rates increased (Figure 7). For example, with no applied K, grain yield increased by 180 kg/ha by increasing N application from 15kg to 80 kg/ha, whereas at 70 kg applied K, the grain yield increased by 377 kg/ha with the additional 65 kg N. At lower N level (15 kg N/ha), there was no grain yield response to added K after 70 kg K/ha. This relationship suggests that it will not be economical to add K without an adequate amount of N fertiliser.

Whilst N and K interact to influence hay yield, they do no interact to influence hay quality. On K deficient soils, increasing K (regardless of N supply) reduces NDF and crude protein and increases WSC of the hay.

The interaction between N x K on hay and grain yield is presented in Figure 7. Under low N fertiliser (15 kg N/ha), applying 70 kg K/ha increased hay yields by only X t/ha
Maintaining adequate amount of N and K nutrition are necessary for optimum grain and hay yields. High rates of K resulted in better grain and hay quality.

As with grain yield, N and K can also interact to influence grain quality. Grain quality is also affected by combined N and K fertilisers. Under low N supply, there is little benefit of K, but with high N supply, a lack of K can affect quality. For example grain hectolitre weight was lower and screenings levels were higher at high amounts of applied N with insufficient K, as illustrated in Figure 8. Higher rates of K also improved average grain weight and groat percentage.

**Nitrogen deficiency symptoms**

Nitrogen deficiency symptoms of oats appear in the early growth stages. Symptoms of N deficiency become more severe as the oat plant grows. When the crop is young, stems are short and thin; leaves and stems are pale green. At flowering, N deficient plants are stunted, have fewer tillers and smaller heads than N adequate plants. At maturity the crop is multi-coloured with upper leaves pale green and middle leaves yellow to pale green with red tips. The oldest leaves may have died, turned brown and fallen to the soil surface. Grain yield is reduced primarily through a reduction in kernels per head and head density.

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**Figure 7.** Interaction between N and K on hay and grain yield (Data are averaged across three oat varieties sown at seven sites grown in 2003 and 2004 seasons, LSD = 0.3 and 0.1 for hay and grain yield, respectively).

**Figure 8.** Increase in hectolitre weight and decrease in screening levels of oat grain due to potassium in the presence of nitrogen. (Data are averaged across three oat varieties sown at seven sites grown in 2003 and 2004 seasons, LSD = 0.2 and 0.5 for hectolitre weight and screenings, respectively).
Water logging and cereal cyst nematode (CCN) damage can give leaf symptoms similar to N deficiency.

**Phosphorus**

Phosphorus is a major nutrient for improved oaten hay and grain production. Phosphorus is a vital component of adenosine triphosphate (ATP), the ‘energy unit’ of plants. ATP forms during photosynthesis and is used from the beginning of seedling growth through to the formation of grain and maturity. Deficiencies result in slow growth, decreased hay and grain yields, inferior quality and subsequently lost income.

It is suggested that P be applied at crop establishment since an adequate supply is critical for rapid development. Phosphorus is needed during early growth for plant root development and elongation, so P fertilisers are drilled with the seed during sowing. An economic response is unlikely if the application is delayed for more than 10 days after sowing.

The oat crop response to P will be influenced by the level of Colwell P and the ability of the soil to retain P (Phosphorous Retention Index). On low P fixing soils (PRI < 2 mL/g, reactive Fe < 280 mg/kg, PBI < 15), P is held very loosely, making it more available to plant roots and potentially reducing the amount of P required for maximum economic yield. On medium and high P fixing soils (PRI 2 to 15 and > 15 mL/g, reactive Fe 280 to 1000 mg/kg and > 1000 mg/kg, respectively) P is held more tightly with a lesser amount available to plant roots. A better response to applied P is expected where soil Colwell tests are low. Soil testing is, therefore, required before deciding what rate of P to apply.

Do hay crops require the same amount of P fertiliser as grain crops? Research conducted in 2002 and 2003 suggests that hay and grain crops may differ in their optimum requirement for P. Hay crops grown on high P fixing soils appear to have a higher requirement for fertiliser P than grain crops. More research however is required to confirm those observations.

Do oat varieties differ in their requirements for P fertiliser? In general the research conducted in 2002 and 2003 suggests that the oat varieties used in those trials (Carrolup, Dalyup, Hotham and Wandering) had similar requirements for P. One trial on a high P fixing soil however found differences between varieties. At that site the P requirements for 90% of maximum grain yield ranged from 16 kg P/ha for Dalyup to 42 kg P/ha for Hotham, with Carrolup requiring 29 kg P/ha and Wandering 22 kg P/ha. Further research is required on the P requirement of oat varieties for both hay and grain at a range of locations before any variety specific changes to P fertiliser management would be suggested.

**Phosphorus deficiency symptoms**

Phosphorus deficiency results in poor seedling establishment and root development. The deficiency symptoms are usually only occur if the deficiency is severe and are more noticeable in young plants as they have a greater relative demand for P than more mature plants.

The tips of the old leaves become dark orange-yellow and this colour moves towards the base, usually along the leaf edges. The affected leaves often have green bases, orange-yellow mid-sections and bright red or purple tips and the edges of the leaves are rolled inwards. In severe deficiency, affected areas die and turn red and purple.
Potassium

Potassium (K) is an important nutrient for oat production. Hay crops remove large amounts of K. Potassium is required for photosynthesis, transport of sugars, enzyme activation and controlling water balance within plant cells. Deficiency of K results in poor root growth, restricted leaf development, fewer grains per head and smaller grain size which affects yield and quality.

Potassium deficiency is more common on lighter textured soils where there is less clay and organic matter to retain the K in the root zone. The deeper sands on coastal plains and peaty sands of south coast are the most prevalent K deficient soils of high rainfall zone of WA. Potassium deficiency is likely to occur if the soil has less than 80 mg/kg of K in the topsoil.

Potassium deficiency can reduce the tolerance of plants to environmental stresses, such as drought, frost and waterlogging, as well as pests and diseases. Potassium deficiency can reduce straw or stalk length leading to lodging problems.

Crop requirements for K change during the growing season. Potassium uptake is low when plants are small and increases during late vegetative and flowering stages. Research in Western Australia has shown that oat yield response to added K depended on the soil extractable K (Colwell K) and environmental conditions. Adding K had a positive effect on quality for hay and grain where soil K levels were low to deficient.

Potassium deficiency symptoms progresses slowly and can be costly if not detected in time. Regular soil and plant analysis and nutrient budgeting can ensure that K deficiency does not occur. Muriate of potash (KCl) is the cheapest form of K. It is applied by top dressing either before seeding or up 5 weeks after seeding. If K deficiency is diagnosed in the soil by Colwell extractable soil test, applying 40 to 80 kg K/ha as muriate of potash (90 to 180 kg/ha) may give an economic yield increase. Potassium at low rates can be banded below or with the seed at sowing, with sulphate of potash safer than muriate of potash. Higher amounts of K drilled with seed can decrease seedling germination, mainly due to salt effect.

Hay crops remove greater amounts of K (about 10 kg K/t) compared to K losses in grain of cereals. The removal of nutrients in hay has to be considered when planning fertiliser requirements for following crops. Practices such as swathing of canola and concentrating and burning of windrows can have significant effects on the spatial distribution of K across the paddock. For these reasons growers should use soil test results in conjunction with plant tissue testing and visual symptoms to determine application rates for paddocks. Decision support tools such as Nu-Logic (CSBP) and KASM (DAFWA) relate soil test values and other soil characteristics to yield potential to give recommended K application rates.

Potassium deficiency symptoms

Potassium is very mobile in plants. In deficient plants K is redistributed to the new growth and the deficiency symptoms first appear in the older leaves. Older leaves turn pale green and bronze and yellow areas develop in the mid-section of the leaf between the edge and mid-vein. These areas quickly extend towards the leaf tip until the top two-thirds of the leaf is bronze-yellow. Grey-brown spots develop within the bronze-yellow areas. Typically, the deficient plant develops a three tone appearance with green younger leaves, green with yellow to bronze colours on the middle leaves and brown older leaves.

Sulphur

Sulphur has an important role in the formation of proteins and is essential for the production of chlorophyll. Crops that have a high N requirement must have adequate S to optimise N utilisation and protein synthesis.

Sulphur deficiency in oat crops is rare in WA, mainly because of the widespread use of superphosphate (11% S). As with N and P, most of the S in the soil is in organic forms. Soils with low amounts of organic matter are prone to S deficiency. Sulphur in organic matter must be mineralised to sulphate before being taken up by roots. Sulphate is
mobile in soils and can be leached out of the rooting zone during winter. Deficiencies therefore mostly often occur in the wetter years. On duplex soils, deficiency symptoms may be only temporary as roots grow into the deeper soil layers where more S is available.

Sulphur deficiency is expected to increase in oat crops in the future as more compound fertilisers containing lower S are used in oat production. Hay production, particularly on sandy soils, is expected to increase the risk of S deficiency as hay crops remove about 1.5 kg S/ha per tonne of hay.

A soil test value of less than 10 mg/kg in the soil surface (0 to 10 cm) may indicate likely S deficiency. However, S in the soil frequently increases down the soil profile, so knowledge of the distribution of S in the soil profile is required. This may involve deeper soil sampling to know the S supply in the soil. Applying P as superphosphate and compound fertilisers that applies S at 5 to 10 kg/ha can avoid S deficiency.

**Sulfur deficiency symptoms**
The youngest leaves of S deficient plants are pale green and then pale yellow across the whole leaf (no striping). Under severe deficiency the entire plant becomes a lemon-yellow colour and stems become red.

**Micronutrients – zinc, manganese and copper**
Micro-nutrients (also called trace elements) are important part of total nutrient management, particularly in no-till systems. Soil test by the DTPA extractant for micronutrients has not been adequately developed for oats grown on soils of WA.

**Zinc**
Zinc is a component of many plant enzymes and essential for healthy plant growth and leaf formation. Oats are highly susceptible to deficient levels of Zn in the soil. After the initial recommended application, most micronutrients have a long residual value in the soil. Therefore, both tissue testing and soil testing, in conjunction, can be used to determine the need for re-application.

Plant symptoms may help to diagnose Zn deficiency. However, a tissue test may be required to diagnose Zn deficiency. Zinc concentrations in the young leaves of less than 14 mg/kg indicate that the plant is Zn deficient.

An initial application of 1 to 2 kg/ha zinc oxide (75 per cent Zn) will correct a deficiency for many years. A foliage spray of 1 kg/ha zinc sulfate (23 per cent Zn) in 50 to 100 L of water should be applied as soon as Zn deficiency is detected to prevent grain and hay yield losses.

**Zinc deficiency symptoms**
Zinc deficiency causes patchy growth, with plants in poor areas stunted with pale green leaves and yellow or orange-red tips. Youngest leaves usually remain green, middle and older leaves turn pale green and pale yellow areas develop between the leaf edge and mid-vein at the tip. Brown spots occur in the affected areas, increasing in size until the leaf tip dies, often turning red-brown to black.

With severe deficiency the stem remains very short and youngest leaves have difficulty emerging fully. The symptoms can be mistaken with that of barley yellow dwarf virus and severe P deficiency.
Manganese
Oats have been found to be highly susceptible to Mn deficiency which can cause significant yield losses. In severe cases, the crop may die entirely.

Tissue tests and visual symptoms can be used to help diagnose Mn deficiency. Mn concentrations less than 20 ppm (mg/kg) in whole shoots indicate Mn deficiency. The concentrations of Mn in tissues vary for different oat varieties (Table 8). The Mn requirement of different oat varieties requires further research work.

Applying manganese sulphate (25% Mn) as a foliar spray at a rate of 4 kg/ha (1 kg Mn/ha in 50 to 100 L of water) immediately symptons appear is usually effective in correcting a Mn deficiency. However, a repeat spray application of Mn may be necessary a few weeks after the first foliar spray for complete control of the deficiency.

The application of ammonium sulphate and ammonium nitrate can markedly reduce Mn deficiency symptoms. Drilling fertilisers enriched with Mn can reduce the risk of crop damage from Mn deficiency. However, even where an ammonium enriched fertiliser has been used severely deficient patches may still require a foliar Mn spray.

Manganese deficiency symptoms
In oats, Mn deficiency produces a condition called ‘grey speck’ which occurs in patches. Oats become pale green and young leaves have spots or lesions of grey/brown necrotic tissue with orange margins. These lesions will coalesce under severe Mn deficient conditions. Plants are weak, stunted, floppy and pale green-yellow and appear water-stress even when adequate soil moisture is available.

Close examination of the leaf frequently reveal slight interveinal chlorosis. The distinction between green veins and yellow interveinal areas is poor. Symptoms can be confused with red leather leaf, which is favoured by prevailing high humidity of high rainfall areas. Symptoms can also be mistaken for take-all.

Copper
Oats are less susceptible to copper deficiency when compared to wheat and barley. However, Cu is essential for growth and development. Plants need Cu to produce new cells and for pollen development (sterile pollen), and hence Cu deficiency severely effects grain yield. Deficient plants that apparently look healthy can produce shrivelled grain reducing both grain yield and quality.

Tissue tests, using the youngest emerged leaf can help diagnose Cu deficiency. Tissue tests with Cu concentrations less than 1.3 mg/kg indicate the plant is severely Cu deficient. Applying 3 to 9 kg/ha of copper sulphate (25% Cu) with fertiliser at seeding in areas suspected to be deficient in Cu correct the deficiency. Copper fertiliser has a long residual in the soil, and a single Cu application at recommended rates can last 20-30 years. Intermittent tissue testing of youngest of oats can maintain Cu at adequate levels.

Copper deficiency symptoms
Copper deficient crops have a patchy appearance with plants in poor areas stunted, pale green and looking limp and wilted even with ample soil water. Late tillers may develop at nodes or joints above ground. Young leaves turn pale green while old leaves remain green. Under conditions of severe deficiency, plants may have leaves which die back from the tip and twist into curls.

The ears of Cu deficient plant are shrunken with gaps such as ‘frosted heads’. The heads of Cu deficient have poor seed-set from sterile pollen thus resulting in ‘white head’, similar to the ear heads affected from drought, heat stress and frost.

Table 8. Plant tissue concentrations (mg/kg) in relation to soil Mn availability. Figures in brackets indicate soil Mn concentration (mg/kg DTPA extractable Mn).

<table>
<thead>
<tr>
<th>Variety</th>
<th>Mn in a healthy plant</th>
<th>Mn in a deficient plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kojonup</td>
<td>10.4 (1.22)</td>
<td>6.7 (0.58)</td>
</tr>
<tr>
<td>Possum</td>
<td>18.4 (0.72)</td>
<td>7.2 (0.50)</td>
</tr>
<tr>
<td>Dalyup</td>
<td>8.3 (0.89)</td>
<td>5.0 (0.51)</td>
</tr>
<tr>
<td>Wandering</td>
<td>10.4 (1.05)</td>
<td>5.1 (0.50)</td>
</tr>
<tr>
<td>Mitika</td>
<td>9.5 (1.2)</td>
<td>-</td>
</tr>
<tr>
<td>Mortlock</td>
<td>6.4 (0.96)</td>
<td>-</td>
</tr>
</tbody>
</table>
Abul Hashem, John Moore

Oats are more competitive with weeds than barley, wheat, canola and pulses when sown at the recommended seeding rates because of a greater tillering ability and leaf area. Increasing crop density also improves the competitiveness of oats against weeds.

Cutting hay is a common method to reduce the weed seed bank. Effective weed management for hay crops is essential as weed contamination reduces hay quality. Contamination by weed plants or weed seeds can cause downgrading or rejection of export hay as there is a weed contamination limit of 5 per cent. There is also a zero tolerance to annual ryegrass toxicity (ARGT) and prickly weeds such as doublegees. In Western Australia, the safe level of ARGT in feed is considered to be 200 to 300 galls per kilogram of grain or hay. The requirement for export hay is strictly less than one gall per kilogram. Hay will be rejected for export if there are one or more galls per kilogram detected.

Pre-seeding weed control is vital as in-crop weed options are limited because oats are more sensitive to herbicides than other crops. Hotham, for example, is sensitive to chlorsulfuron and can experience more than 10 per cent yield loss when chlorsulfuron is applied at recommended rates. Mortlock and Carrolup are also very sensitive to phenoxy herbicides such as 2,4-D and MCPA.

It is better to slightly delay sowing to spray weeds with a knockdown herbicide than sowing early and trying to carry out in-crop weed control. If in-crop weed control is required, spray as soon as the crop is old enough to cope with sprays (before the plant reaches the growth stage Z32) and while the weeds are as small as possible.

Weed control before sowing

The following herbicides provide a good knockdown of a variety of weeds ranging from annual ryegrass to capeweed:

- glyphosate e.g., (Roundup® Powermax)
- paraquat / diquat (e.g., Spray.Seed® 250)
- paraquat (e.g., Gramoxone®)

These above herbicides can be ‘spiked’ with the following herbicides to provide improved weed control (note: observe the plantback period stated on labels prior to sowing. Check labels for appropriate mixing ratios):

- 2,4-D amine
- 2,4-D LVE ester
- carfentrazone-ethyl (e.g., Hammer®)
- clopyralid (e.g., Lontrel®)
- dicamba (e.g., Kamba®, Cadence®)
- diuron
- metosulam (e.g., Eclipse®)
- metsulfuron (e.g., Ally®)
- oxyfluorfen (e.g., Goal®).

Registered herbicides for pre-emergent weed control

- clopyralid (e.g., Lontrel®)
- metolachlor (e.g., metolachlor)
- s-metolachlor (e.g., Dual Gold®)
- oxyfluorfen (e.g., Goal®)
- diuron (e.g., Diuron 900WDG)
Weeds that can be controlled by pre-emergence herbicides include annual ryegrass, barley grass, silver grass, capeweed, crassula, doublegee, mustards, toad rush, and wild radish.

Registered herbicides for post-emergent weed control

Table 9 lists the herbicides that are registered for use in emerged oat crops to control either grasses or broad-leaved weeds. Weeds that can be controlled at post-emergence include:

<table>
<thead>
<tr>
<th>Active chemical (trade name example)</th>
<th>Rate</th>
<th>Crop and weed stages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grasses and monocot weeds</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>chlorsulfuron 750 g/kg (e.g. Glean®)</td>
<td>15 to 25 g/ha</td>
<td>Crop: 2 leaf stage to early tillering (see label for Mortlock oats). Weed: No later than 3 leaf stage for annual ryegrass.</td>
</tr>
<tr>
<td><strong>Broad-leaved weeds</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bromoxynil 200 g/L (e.g. Bromicide®)</td>
<td>1.4 to 2.1 L/ha</td>
<td>Crop: From 3 leaf to jointing.</td>
</tr>
<tr>
<td>bromoxynil/dicamba/MCPA 140/40/280 g/L (e.g. Broadside®)</td>
<td>0.75 to 1.4 L/ha</td>
<td>Crop: From 3 leaf to jointing.</td>
</tr>
<tr>
<td>bromoxynil/MCPA 200/200 g/L (e.g. Buctril® MA)</td>
<td>0.75 to 2.0 L/ha</td>
<td>Crop: From 3 leaf to jointing.</td>
</tr>
<tr>
<td>carfentrazone-ethyl 240 g/L (e.g. Affinity®)</td>
<td>65 to 100 g/ha</td>
<td>Crop: 3 leaf to mid-tillering. Add 500 mL/ha MCPA amine for certain weeds. See label.</td>
</tr>
<tr>
<td>chlorsulfuron 750 g/kg (e.g. Glean®)</td>
<td>15 to 25 g/ha</td>
<td>Crop: From the 2 leaf stage. Weed: No later than 3 leaf for ryegrass.</td>
</tr>
<tr>
<td>clopyralid 750 g/L (e.g. Lontrel® 750)</td>
<td>60 to 120 g/ha</td>
<td>Crop: 2 leaf to jointing.</td>
</tr>
<tr>
<td>dicamba 700 g/kg (e.g. Cadence®)</td>
<td>115 g/ha (add 7 g/ha Eclipse® for some weeds). 200 g/ha (MCPA, 2,4-D or Eclipse® additions may be needed)</td>
<td>Crop: From 3 leaf to early tillering. Crop: From 5 leaf to early tillering. Check label carefully for mixture and oil rates.</td>
</tr>
<tr>
<td>difluufenican/MCPA 25/250 g/L (e.g. Tigrex®)</td>
<td>0.25 to .75 L/ha</td>
<td>Crop: From 5 leaf to late tillering.</td>
</tr>
<tr>
<td>diuron 500 g/L</td>
<td>300 mL/ha [+ 400 mL/ha MCPA amine (500 g/L)]. 400 mL/ha [+ 500 mL/ha MCPA amine (500 g/L)]. 500 mL/ha [+ 250 mL/ha 2,4-D amine (500 g/L)].</td>
<td>Crop: 3 to 4 leaf stage, no later than 6 weeks after sowing. Crop: 4 to 5 leaf stage, no later than 6 weeks after sowing. Crop: 4 to 6 leaf stage, no later than 6 weeks after sowing.</td>
</tr>
<tr>
<td>diuron 900 g/ha DF</td>
<td>200 g/ha [+ 400 mL/ha MCPA amine (500 g/L)]. 280 g/ha [+ 250 mL/ha 2,4-D amine (500 g/L)].</td>
<td>Crop: From 3 to 5 leaf stage on. Crop: From 4 to 6 leaf stage on.</td>
</tr>
<tr>
<td>flumetsulam 800 g/kg (e.g. Broadstrike®)</td>
<td>25 g/ha. Add 100 mL/ha diuron for capeweed.</td>
<td>Crop: 3 leaf to jointing. Add wetter.</td>
</tr>
<tr>
<td>metosulam 714 g/kg (e.g. Eclipse®)</td>
<td>5 to 7 g/ha</td>
<td>Crop: 2 leaf to jointing. Add spraying oil.</td>
</tr>
<tr>
<td>MCPA amine 500 g/L</td>
<td>0.9 to 2.0 L/ha</td>
<td>Crop: From 5 leaf to flag leaf emergence.</td>
</tr>
<tr>
<td>MCPA low volatile ester 500 g/L</td>
<td>0.5 to 1.6 L/ha</td>
<td>Crop: 3 leaf to flag emergence.</td>
</tr>
<tr>
<td>MCPA/Picolinafen 500/50 g/L (e.g. Paragon®)</td>
<td>250 to 500 mL/ha</td>
<td>Crop: 3 to 5 leaf.</td>
</tr>
<tr>
<td>triasulfuron 750 g/kg (e.g. Logran®)</td>
<td>10 to 15 g/ha</td>
<td>Crop: 3 leaf to tillering. Weed: Wild radish 2 to 6 leaf. Add a spraying oil.</td>
</tr>
<tr>
<td>2,4-D amine 300 g/L (e.g. Surpass® 300)</td>
<td>1.1 to 3.3 L/ha</td>
<td>Crop: 5 leaf to jointing.</td>
</tr>
<tr>
<td>2,4-D amine 475 g/L</td>
<td>0.8 to 1.6 L/ha</td>
<td>Crop: From 5 leaf to flag leaf emergence.</td>
</tr>
<tr>
<td>2,4-D amine 825 g/kg (e.g. Amicide® 625)</td>
<td>0.64 to 1.3 g/ha</td>
<td>Crop: From tillering to boot stage. Apply after 6 leaf stage in Mortlock oats.</td>
</tr>
</tbody>
</table>
annual ryegrass, cape tulip, capeweed, clover, dock (seedlings), Guildford grass, corn gromwell, doublegee, flatweed, fumitory, London rockets, lupins (volunteer), mallows, matricaria, medics, mustards, Paterson curse, prickly lettuce, rough poppy, turnip weed, saffron thistle, skeleton weed, sow thistle, wild turnip, wireweed, and yellow burrweed.

Further information about variety resistance to herbicides can be found on the oat web pages (<www.agric.wa.gov.au>). Herbicide recommendations can be found in the latest Cereal Spray Charts: at DAFWA offices in e-weed and Planfarm Herbicide Guide. E-weed is a free newsletter service from DAFWA providing information on weed control issues throughout the growing season.

**Integrated weed management**

Preventing weeds from entering or establishing in a paddock is the best method of weed management. This can be achieved by non-chemical methods such as:

- use weed-free seed. Ask for a seed analysis report
- clean machinery when moving between paddocks on farms
- graze weeds with sheep or cattle
- cut for silage or hay
- use weed-free feed
- increase seeding rates to maximise crop/weed competition
- use chaff carts to collect weed seeds at harvest
- use Harrington seed destructor at harvest time in grain crops
Diseases

Dominie Wright, Geoff Thomas, Kithsiri Jayasena

Foliar diseases

The major foliar diseases of oats in Western Australia are septoria blotch, leaf rust, stem rust and barley yellow dwarf virus. Other minor diseases include ring spot and the bacterial disease stripe blight. All of these diseases have the ability to reduce the yield and quality of hay and grain in conditions favourable for disease development. Oat crops should be actively monitored for these diseases.

When diagnosing oat diseases, it is important to look at the big picture and assess overall what is happening in the paddock.

Disease development depends on:
• presence and abundance of the pathogen (green bridge, oat stubble, infected seed).
• susceptibility of the oat variety to the disease (varieties can have different levels of resistance to different diseases).
• suitable environmental conditions (high rainfall generally favours foliar diseases).

Septoria avenae blotch

Septoria blotch is the most common oat disease in Western Australia. This disease is caused by the fungus Phaeosphaeria avenaria (asexual stage: Stagonospora (formerly Septoria) avenae). The disease is carried between seasons on infected stubble.

The fungus infects leaves, leaf sheaths and stems and under high disease pressure may also infect heads. Infected leaves have mottled light to dark brown-purple roughly circular blotches, with dark brown centres that gradually enlarge and coalesce to cover most of the leaf as the infection becomes more severe (Figure 9).

Figure 9. Oat leaves infected by Septoria avenae blotch (Photo: Raj Malik, DAFWA).
Similar lesions occur on the leaf sheath and when severe these lesions can extend into the stem causing death and blackening which may lead to lodging. The fungus sometimes causes a dark discolouration of the grain when unseasonably late rain occurs. Septoria avenae blotch can cause up to 50 per cent yield loss in extreme cases but losses of around 10 per cent are more common in high rainfall areas.

The disease is stubble-borne, therefore greatest disease risk is associated with continuous oat crops. Rotating crops and sowing oats following a non-host will reduce the occurrence of septoria. Burning or incorporating stubble prior to sowing will reduce risk of early infection in continuous oat paddocks. Tall or slow maturing oats are less likely to be affected compared to dwarf or fast maturing varieties. Varieties differ in their resistance to this disease. Sow more resistant varieties in high disease risk paddocks.

Foliar fungicides are registered for septoria suppression and can provide some protection of yield and quality of grain or hay.

**Leaf rust**

Leaf rust or crown rust is caused by the fungus *Puccinia coronata* f.sp. *avenae*. Round to oblong pustules (lesions) that are orange to yellow in colour develop primarily on the leaves but occasionally on leaf sheaths and heads of infected plants (Figure 10). The powdery spore masses in the pustules are readily dislodged and are spread by wind, disease can multiply rapidly with favourable conditions or in a susceptible host (Figure 11 Leaf rust spore cloud in oats). As they age, the pustules then turn black and lose the powdery spore masses.

Leaf rust is a green bridge disease; it requires a living host to survive between seasons. Disease risk is highest in seasons following wet summer / autumn which will favour survival of rust inoculum on volunteer hosts, and wild oats. Grazing, spraying or tilling to control volunteer oats over summer may help to reduce leaf rust but the effect can be limited by the abundance of wild oats that also act as
a green bridge. Variety resistance is very effective therefore avoid planting highly susceptible oat varieties in rust-prone areas or in the presence of a green bridge. Foliar fungicides are registered for leaf rust management however; ensure that withholding periods for both hay and grain are considered in timing of application.

**Stem rust**

Stem rust is caused by the fungus *Puccinia graminis* f.sp. *avenae* and is one of the most severe diseases of oats. Its life cycle and management is similar to leaf rust. Affected plants have oval or elongated reddish-brown pustules mainly on their stems but also on leaves and heads (Figure 12). The pustules are larger than those of leaf rust. Lesions produce masses of powdery spores which can dislodge readily and are spread by wind. Stem rust is favoured by warm moist weather; infection can increase rapidly in wet spring conditions.

Similar to leaf rust, variety resistance can effectively reduce rust development, avoid planting highly susceptible varieties in rust-prone areas or in seasons with high rust risk. Before sowing oats, control volunteer weeds and plants that may act as a green bridge for the diseases over summer. Foliar fungicides are registered for stem rust in oats; although control can be difficult, withholding periods need to be considered in timing of application.

**Virus Diseases**

*Roger Jones*

**Barley yellow dwarf virus**

Barley yellow dwarf virus (BYDV) is widespread in high rainfall areas of the state. It infects cereals and grasses. The virus survives between cropping seasons in grasses or volunteer cereals which persist outside the growing season, acting as a green bridge. Infection is spread from grass reservoirs and volunteer cereals to crops through the migration of cereal and grass aphids, especially the oat aphid, *Rhopalosiphum padi*. Due to the role of aphids in establishing infection, BYDV is always more severe following wet summers when volunteer hosts are abundant and substantial aphid build-up and BYDV spread has occurred prior to sowing.

Plants infected with BYDV have yellow-brown or orange-brown discoloration near the leaf tip, especially on lower leaves. The discoloration spreads until most of the leaf is affected and appears red-brown. Later it changes to a crimson-pink (Figure 13). The distribution of infected plants across the paddock is normally patchy but occasionally the whole crop may show symptoms.
Infection at all growth stages can be damaging, however infection occurring early in the crops growth has greatest potential for crop damage. Oats infected with BYDV as seedlings show additional symptoms of severe stunting, increased tillering and floret abortion.

To reduce risk of BYDV infection, sow more resistant oat varieties. The planting date can also be adjusted so that young crops aren’t exposed to periods of high aphid numbers; however, the benefit of this strategy needs to be weighed up against yield penalties from delayed sowing.

Once aphids contract the virus they remain infected for the rest of their lives. Hence in high risk seasons it is critical to prevent the spread of the virus in the first eight to ten weeks after crop emergence, when there is the greatest potential for crop damage, by applying insecticides to eradicate aphids. In high risk aphid years (with a summer/autumn green bridge or in disease prone regions), anti-feeding insecticides (alpha-cypermethrin) should be applied at 3 and 7 weeks after emergence regardless of whether aphids can be seen on the plants. A web based forecasting system is available which shows which localities need these sprays and which don’t in any particular year. It is recommended that you reassess your disease risk at seeding by viewing the crop disease forecasts on the DAFWA website at www.agric.wa.gov.au/cropdisease.

**Bacterial blights**

There are two types of bacterial disease which infect oat foliage; halo and stripe blight.

**Halo blight** (*Pseudomonas syringae pv. coronafaciens*) causes light green-coloured, oval-shaped spots up to 10 mm surrounded by a pale halo with a water-soaked appearance. Spots turn brown and fuse together into blotches (Figure 14).

**Stripe blight** (*Pseudomonas syringae pv. striafaciens*) forms long, red-brown stripes on leaves during winter (Figure 15), which join into blotches that cause leaf collapse (blight). It is easy to confuse this disease with Septoria avenae blotch.

Stripe blight is most common in continuous oaten hay crops and is prevalent with extended periods of moist weather which facilitates splash of bacteria and provides suitable conditions for infection. The disease is favoured when crop density is high and there has been a high input of nitrogen making the plants soft. As the growing season progresses, plants generally grow away from this disease. Warm dry spring conditions will rapidly reduce spread of this disease. Unless infection is very severe, yield losses are not known to be significant. The disease will lower the quality of the hay.

There is no chemical control for this disease (fungicides are not registered or effective against bacterial diseases). As a management tool avoid sowing into infected stubbles and burn or incorporate stubble if the problem is widespread. The disease can be seed borne, do not re-sow seed from infected crops. To prevent disease spread, paddock hygiene is important. Therefore, paddock operations should be avoided when leaves are wet.

**Ring spot**

Ring spot is a common disease which is widespread throughout agricultural areas. The fungus infects leaves and occasionally leaf sheaths causing small ring spots with dark rims and bleached tan centres. It has a wide host range and produces similar symptoms on a range of other cereals and grass weeds. Fungus-infested stubble produces spores which spread to nearby plants; spores produced on infected leaves do not spread the disease to other leaves. The disease is most common where grass weeds have been common in the previous season. It is not known to reduce yields and no direct control measures are available.
Loose and covered smut

Loose smut (*Ustilago avenae*) and covered smut (*Ustilago hordei*) of oats are seed-borne diseases with similar symptoms which are difficult to distinguish in the field. Both diseases are managed in the same way. In affected plants each spikelet is transformed into a mass of dark brown to black spores which is at first contained within a fine membrane. After head emergence, this membrane bursts releasing the spores to contaminate healthy heads, leaving a bare stalk or rachis on the infected plant. Spores are carried on infected seeds between seasons. After sowing, spores on the seed surface germinate and infect the emerging seedling, growing without symptoms within the plant and infecting the developing head completing the disease cycle. These diseases are well-managed by regular application of fungicide seed dressing and replacement of contaminated seed stocks.
Chemical control of foliar diseases

Despite the effort to improve the resistance of oat varieties to leaf diseases, there is seldom complete resistance or varieties may not have a complete suite of resistance to all diseases. Therefore agronomic solutions must be used to reduce the impact of leaf diseases. Fungicide applications are becoming an increasingly important part of disease control strategies. However, currently in Western Australia there are limited control options available for oats for use as foliar sprays in oat crops. There are only two fungicide active ingredients registered for use as foliar sprays in oat crops: propiconazole and tebuconazole which control leaf and stem rusts. Only propiconazole is registered to suppress septoria.

Root and crown diseases

Root and crown diseases such as rhizoctonia bare patch (*Rhizoctonia solani*), take-all (*Gaeumannomyces graminis* var. *avenae*) and Fusarium crown rot (*Fusarium pseudograminearum*, *Fusarium culmorum*) frequently occur in Western Australian cropping systems. These diseases are often harder to detect and diagnose than foliar diseases, above ground symptoms are often indistinct. Lack of vigour or patches in crops are a common symptom of these diseases. In many cases disease symptoms can be confused with nutrient deficiencies, herbicide damage or soil constraints. However, these diseases must be identified correctly to enable appropriate control measures to be implemented.

Disease symptoms on roots are usually distinctive and when combined with paddock symptoms, accurate diagnosis can be achieved. The potential for damage by several key root and crown diseases can be tested by a soil test. The Predicta B soil test provides an analysis of soil inoculum levels by measuring the level of fungal DNA of pathogens such as rhizoctonia, take-all, cereal cyst nematode, root lesion nematodes (only *P. neglectus* and *P. thornei*), stem nematode and crown rot.

**Rhizoctonia bare patch**

Rhizoctonia bare patch has a wide host range and attacks most crop, pasture and weed species common in WA farming systems. Above ground symptoms appear as roughly circular patches with distinct edges which become apparent 3-4 weeks after sowing. The bare patches can vary in size from less than half a metre up to several metres across. Roots of affected plants are short with brown, pinched ends (spear tips). Plants within patches may have a purple tinge to their leaves. Yield loss is usually proportional to the area of paddock affected by patches.

Deep cultivation at sowing with a narrow tine below seed or deep ripping immediately prior to sowing is the most effective methods of reducing damage caused by this disease. Ensuring good crop growth through adequate plant nutrition and avoiding herbicide damage to roots will reduce the impact of this disease. Fungicide seed dressings are registered for suppression of this disease and these should be used in conjunction with other control strategies. Crop rotation and variety resistance are do not affect bare patch.

**Fusarium crown rot**

Crown rot is a fungal disease which survives between seasons on infected stem and crown residues in soil. Infection in crops is usually first seen after flowering when whiteheads develop. Single tillers, whole plants or groups of plants can be affected. The lower stem of affected plants has a honey brown to dark brown discolouration at the stem base. Moisture stress after flowering exacerbates the development of whiteheads in infected crops. Oats are less susceptible than wheat and often no symptoms are seen, particularly in hay crops, although oats can build up disease levels for subsequent wheat crops.
Take-all
Oats are not susceptible to the wheat take-all fungus. There is an oat form of take-all which can cause some damage to oat crops, although it does not commonly cause significant levels of damage. The characteristic symptoms of Take-all are a black root rot (blackening both the surface and the centre of the root), associated with a blackening around the base of the stem and subsequent premature ripening of plants causing whiteheads in severely affected plants.

Crop rotation is the main control for take-all. A one-year break from oat, wheat or grass hosts is usually enough to reduce inoculum.

Further detailed information on root and crown diseases is available in DAFWA Bulletin 4732: Root disease under intensive cereal production systems.

Nematodes

Vivien Vanstone

Nematodes are common soil pests that feed on the roots of a wide range of crop plants in all agricultural areas of Western Australia, irrespective of soil type and rainfall. Nematodes multiply on susceptible hosts. Consequently, as nematode populations increase, crop production is limited. Cereal yield losses due to nematodes in Western Australia are in the order of 5 to 25 per cent per annum, but much higher losses to individual crops have been recorded.

When roots are damaged by nematodes, water and nutrient uptake are less efficient, and plants are also less able to tolerate other stresses such as drought. With adequate soil nutrition and moisture, particularly in spring, damaged roots may be able to extract sufficient nutrients to grow and finish well. Plants affected by nematodes can be more prone to attack by fungi that cause leaf and root disease.

In-field diagnosis of nematodes is not easy, as above-ground symptoms of infection are difficult to detect. Plants may show a combination of indistinctive symptoms, all of which can be confused with, or exacerbated by, nutrient deficiencies:

- uneven growth and yellowing;
- stunting and decreased tillering;
- wilting under water stress.

Nematodes are usually distributed unevenly across a paddock, resulting in irregular growth or patchiness. Laboratory testing of plants or soil is often necessary to determine the numbers and type(s) of nematodes present. Nematodes are microscopic (less than 1 mm in length) so cannot be seen with the naked eye (Figure 16).

Cereal cyst nematode

The cereal cyst nematode (*Heterodera avenae*) can cause severe damage in areas where continuous cereal cropping is favoured. In Western Australia, cereal cyst nematode (CCN) is reported frequently from the Northern Agricultural Region around Geraldton and from the Central Agricultural Region but it can occur in any area.

CCN only infects cereals and other grasses (particularly wild oat).
In infected paddocks, the female nematodes invade the plant roots in autumn. As the females feed and develop within the roots, their bodies swell and erupt through the root surface. They can then be seen as white, spherical bodies about the size of a pinhead on the root surface (Figure 17). At this stage, the female nematodes each contain several hundred developing eggs.

The cysts turn brown and remain in the soil over summer, where the eggs will hatch at the start of the next season. CCN needs a combination of moist and cool conditions to hatch. However, only 70 to 80 per cent of these eggs hatch each season, so some will remain in the soil for following seasons, even where no hosts are available. For this reason, it can take several years for high CCN populations to be reduced below levels which are yield limiting.

**Symptoms**

Above-ground symptoms can be indistinct, consisting of patchy and uneven growth. Plants can also appear stunted, unthrifty and yellowed. Development of the whole root system is retarded. The roots of oats will appear ‘swollen’ and ‘ropey’ (Figure 18).

With heavy infestation, CCN will cause distinctive patches of yellowed growth (Figure 19). These patches can increase in size and severity with successive cereal crops.

**Management strategies**

**Variety selection.** Oat varieties differ in their ability to host nematodes. Resistant varieties act as excellent break crops which limit nematode multiplication, while susceptible varieties increase the severity of the disease. However, varieties also differ in their ability to develop normally and produce hay in the presence of the nematode: oat varieties range from moderately tolerant to very intolerant. Tolerant varieties will develop normally in the presence of high nematode populations but in the same situation intolerant varieties would have poor growth or could even die (Figure 20). Therefore, if nematodes are a problem it is advisable to select a variety with both resistance and tolerance. Oats can be very sensitive to CCN, so only a low level of nematodes can cause significant damage to an intolerant variety.

**Rotations** of legume crops, canola or grass-free pastures with cereals are effective. Since CCN can only infect cereals and other grasses, rotations incorporating non-cereals and good control of grass weeds are an effective break. In infected areas, do not grow more than two consecutive cereal crops following a non-host break crop. However,
severe soil infestations may require more than one year of a non-host crop to reduce CCN below yield limiting levels.

**Plant clean break crops.** Control susceptible cereal volunteers and grasses (particularly wild oat) in non-host phases of rotations.

**Use soil testing** to monitor nematode numbers and maintain low levels with rotations.

**Chemical treatments** for nematode control in cereal crops are not currently available. These chemicals are expensive and highly toxic to humans.

**Cultivation** is NOT an effective control option. This spreads the nematodes around the paddock and distributes them throughout the soil profile making the problem worse.

**Root lesion nematode**

Root lesion nematode (*Pratylenchus species*) inhabits soil and feeds on the roots of plants. Several damaging species of *Pratylenchus* occur in cropping areas of Western Australia: *Pratylenchus neglectus*, *P. teres*, *P. penetrans* and *P. thornei*. Population densities of all root lesion nematode (RLN) species will increase under intensive cereal production. These nematodes occur across the entire wheatbelt.

At least 60 per cent of Western Australia’s cropping paddocks are infested with one or more species of RLN, and about 40 per cent of these are at levels which may cause yield losses in the order of 5 to 25 per cent. There have been individual cases of losses as great as 40 per cent. In Western Australia, *P. neglectus* is the most commonly identified species (detected in 40 per cent of paddocks), followed by *P. teres* (detected in 10 per cent of paddocks). *P. penetrans* has been identified in some crops, including oat.
where it can cause significant root damage (Figure 21). *P. thornei* is rare in Western Australia. More than one species of RLN can occur in a single paddock. All species of RLN cause identical root symptoms.

For nematode diseases, particularly RLN, the resistance of a crop species or variety is determined by the plant’s ability to inhibit or support nematode reproduction. Resistant varieties can be used to reduce the nematode population over one or more seasons. However, resistant crops will not eliminate RLN and will still support low nematode levels. For this reason, the nematode population can quickly increase again when a susceptible crop is sown.

**Symptoms**

Above-ground symptoms of nematode infection are often indistinct and difficult to identify. Affected plants are stunted and tiller poorly, and may wilt despite moist soil. Crops will appear patchy with uneven growth (Figures 22 and 23). Roots may have indistinct brown lesions or, more often, generalised root browning (Figure 24). When roots are infested with high numbers of RLN, they are thin and poorly branched. Lateral root branches are reduced in both length and number. Sections of the root system may appear dead, with the crown roots often less affected than the primary roots.
Management strategies

Root lesion nematode can be managed with rotations and other cultural practices but cannot be eradicated. The first step towards effective management of nematode diseases is correct identification of the species present. Extraction and identification of nematodes needs to be carried out in a laboratory to confirm the RLN species present and their population density.

Rotations that include resistant crops in the sequence are the most effective means of reducing the number of RLN in soil, or preventing its build-up. Rotations need to be tailored to the predominant RLN species present. To maintain low nematode population densities, avoid continuous cropping with susceptible cereal crops. Crops resistant to *P. neglectus* include field pea, faba bean, narrow-leafed lupin, lentil, rye and triticale.

Use resistant varieties. Most oat varieties are Moderately Resistant to *P. neglectus*. Oats is, however, more susceptible to *P. penetrans*. Further information can be found in annual DAFWA and SARDI variety and disease guides.

Focus weed control on controlling susceptible weeds (particularly wild oat, barley grass, brome grass and wild radish) and susceptible volunteers (especially cereals) to reduce RLN build-up and carryover.

Pesticides for nematode control in cereal crops are not currently available. These chemicals are expensive and highly toxic to humans.

Soil and plant testing services

To determine whether a fungal or nematode root disease is affecting a cereal crop, first look at the distribution of symptomatic plants throughout the whole crop. Next, carefully dig up samples of apparently diseased as well as healthy plants. Thoroughly wash the soil from the roots and examine them for any indicative symptoms.

Suspected root disease or nematode problems in-crop can be confirmed by laboratory analysis of soil and/or roots. For patch diseases, sample from the edge of the patch rather than the centre. Do not send washed plants to the laboratory. Follow sampling guidelines at http://www.agric.wa.gov.au/PC_90018.html?s=709641941.

Growing season tests are carried out on affected plants and associated soil. Although little can be done during the growing season to correct a fungal or nematode root disease, it is important to identify the cause of the problem so that decisions on appropriate management strategies can be taken leading up to and during the following seasons. Test kits are available from AGWEST Plant Laboratories and participating distributors. To obtain submission forms and full sampling instructions, contact your local DAFWA office. Information can be found at http://www.agric.wa.gov.au/PC_90018.html?s=709641941 or by phoning 08 9368 3721 or emailing agwestplantlabs@agric.wa.gov.au.

Pre-season assessment. The risk of root diseases being present in a paddock at a yield limiting level next season can be determined by paddock history, paddock monitoring in spring or soil tests. A review of paddock history will identify the diseases likely to be present in each paddock. The level of disease likely to develop can be determined by digging up plants in spring from areas of poor growth and examining the roots for symptoms. An informed decision can be made about the future use of each paddock based on the presence or absence of a disease and the conduciveness of the current season and crop to further develop that disease. Pre-season soil tests can be used where the paddock history is not adequate for planning future use. Soil tests are conducted on representative soil samples. PreDicta-B uses DNA assessment to determine the root diseases or nematode species present, and the likely risk of crop damage. Test kits are available through accredited agronomists and re-sellers, by contacting alan.mckay@sa.gov.au Ph 08 8303 9375 or at http://www.sardi.sa.gov.au/pestsdiseases/diagnostic_service/predicta_b.
Insect and allied pests of oats

Svetlana Micic, Peter Mangano, Chris Newman

Field pests
A vigorously growing oat crop with adequate plant densities (at least 240 plants per square metre for an oat crop; 320 plants per square metre for a hay crop) is able to withstand considerable pest damage with little yield loss. Where sowing depth has been too deep or crops are moisture stressed pest damage is greater.

Oat crops should be checked regularly to enable control measures to be taken early and prevent excessive damage especially at the seedling stage.

It is important to correctly identify the pest causing the damage so appropriate control measures may then be taken. To assist in this process, the appearance and type of damage caused by caterpillars, lucerne fleas, mites, slugs, snails, aphids, earwigs and beetles (referred to as invertebrates) is described and their management is discussed.

A key to the damage cause by major pests to oats can be found on next page.

Descriptions of pests, their thresholds and control measures can be found in Table 10.

A table of registered insecticides can be found in Table 11.

For pests not covered by this publication, refer to your local Department of Agriculture and Food Office for advice.

Chemical control
Routine spraying without monitoring pest numbers may increase the likelihood of insects developing resistance to insecticides. Consider spraying, only if there is economic damage occurring to your crop.

Prior to spraying your crop, consider the amount of damage occurring. A good idea is to consider the suggested thresholds in Table 10.

A good way to find out the extent of insect damage is to monitor a number of random sites within a paddock. The more sample sites the better. Pests are not always uniformly distributed in a crop. Sampling only one or two sites may give a misleading impression of pest density.

Table 11 shows the rates of insecticides that are registered for use in oats against common pests.

Vagrant invertebrates in harvested grain and hay
Vagrant invertebrates are those that are incidentally harvested with the grain. They do not damage grain. However, there is a zero tolerance to invertebrates in export hay.

Most common vagrant invertebrates
One of the most common contaminants of cereal grain is the bronzed field beetle (*Adelium brevicorne*)

Other common vagrant invertebrates include: predatory beetles, vegetable beetles, snails, weevils, grasshoppers, earwigs and ladybeetles.
Insect and allied pests of oats

Crop damage to seedlings

**Chewed above ground**

- Whole plants or parts of leaves eaten
  - Irregular pieces or shredded leaves
    - Snails: Usually found close to damage near plants
    - Slugs: Are restricted to heavier soils found under stubbles, plant matter
    - European earwigs: Easily found under dead plant matter, rocks

- Leaves chewed, some plants cut off at ground level
  - Portions of plant material protruding from tunnel
    - Yes
      - Webworm
    - No
      - Cutworm
      - Lucerne flea
      - Balaustium mite
      - Earthmites
      - Cockchafer
      - Desiantha larvae

**Holes in leaves usually with white film**

- Cotyledons with bleached patches on leaves
  - Large easy to see mites: YES
  - Small black mites: NO
  - C-shaped grubs present in soil
    - YES
    - Check for aphids under leaves
    - NO

**No chewing evident**

- Poor seedling growth - stunted or dying
  - Root System Chewed: YES
  - NO
TABLE 10. Identification of oat pests and cultural control options

<table>
<thead>
<tr>
<th>Pest</th>
<th>Appearance</th>
<th>Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seeding pests</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aphids: Corn aphid</td>
<td>Corn aphids are dark blue-green to grey green.</td>
<td>Are vectors of barley yellow dwarf virus, refer to Diseases section.</td>
</tr>
<tr>
<td>(Rhopalosiphum maidis), oat/wheat aphid (R. pad)</td>
<td>Oat aphids vary in colour from olive green to blackish green but all have reddish patch on the tip of their backs.</td>
<td>Plants are most vulnerable to the effects of the virus within the first 8-10 weeks after emergence.</td>
</tr>
<tr>
<td>Aphids: Southern armyworm (Leucania convecta)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cockchafers:</td>
<td>Cockchafer larvae are ‘c’ shaped creamy, white grubs that range in size from 5-20 mm.</td>
<td>Cookchafer larvae feed underground on plant roots.</td>
</tr>
<tr>
<td>(Heteronyx obsesus)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Webworm (Hednota spp)</td>
<td>Pale to deep brown body colour with dark head. Up to 15 mm in size, found in web lined tunnels.</td>
<td>Sever leaves or whole plants which they scatter on the ground or pull into holes at the base of plants.</td>
</tr>
<tr>
<td>Caterpillars:</td>
<td>Stout-bodied caterpillars up 50 mm in size found in soil at the base of plants.</td>
<td></td>
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<tr>
<td>(Agrotis spp.)</td>
<td></td>
<td></td>
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<tr>
<td>Mites:</td>
<td>Round body (up to 2 mm) with stout hairs, brown-red in colour.</td>
<td>Bleached white lesions on seedling leaves.</td>
</tr>
<tr>
<td>Balaustium mite</td>
<td></td>
<td></td>
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<tr>
<td>(Balaustium medicagoense)</td>
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<td></td>
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<tr>
<td>Earthmites:</td>
<td>Very small mites up to 1 mm with a black body and red legs.</td>
<td>Leaves appear bleached.</td>
</tr>
<tr>
<td>Redlegged earth mite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Halotydeus destructor)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue oat mite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Penthalus spp.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slugs:</td>
<td>Black keeled slugs are black in colour; Reticulated slugs are light grey in colour.</td>
<td>Chewed leaves or whole plants. They sometimes feed on lupin seeds at seeding. Slime trails may sometimes be seen.</td>
</tr>
<tr>
<td>Black keeled slug</td>
<td></td>
<td></td>
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<tr>
<td>(Milax gagates)</td>
<td></td>
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</tr>
<tr>
<td>Reticulated slug</td>
<td></td>
<td></td>
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<tr>
<td>(Dicerocera reticulata)</td>
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<td></td>
</tr>
<tr>
<td>White Italian snail</td>
<td>White Italian snails have white shells, mostly with broken brown bands in the line of the spiral. Some are all white. Shells are up to 24 mm in width.</td>
<td>Chewed leaves. Slime trails may sometimes be seen.</td>
</tr>
<tr>
<td>(Theba pisana)</td>
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<tr>
<td>Vineyard snail</td>
<td>Vineyard snails have shells up to 20 mm wide with a continuous brown band.</td>
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<tr>
<td>(Cernuella virgata)</td>
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<tr>
<td>Small pointed snail</td>
<td>Small pointed snail has a light brown conical shell up to 10 mm long.</td>
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</tr>
<tr>
<td>(Cochlicella barbara)</td>
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<td></td>
</tr>
<tr>
<td>Weevil:</td>
<td>Larval stage attacks cereals, larvae are white, legless, 6 mm long with orange brown heads.</td>
<td>Feed on underground part of plants, leading to slow plant growth or plants may stop and die and are easily pulled from the ground.</td>
</tr>
<tr>
<td>Aphids:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Rhopalosiphum maidis), oat/wheat aphid (R. pad)</td>
<td>Corn aphids are dark blue-green to grey green. Oat aphids vary in colour from olive green to blackish green but all have reddish patch on the tip of their backs.</td>
<td>Heavy infestations can blacken heads and flag leaves, cause yield losses by reducing grain weight.</td>
</tr>
<tr>
<td>Caterpillars:</td>
<td>Brown caterpillars with 3 longitudinal white stripes on collar behind head, grow up to 40 mm in size. Have green to straw coloured droppings size of match head, usually found in crop rows.</td>
<td>Chew particle causing grain to fall.</td>
</tr>
<tr>
<td>Armyworm:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most common are-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inland army worm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Persectania dyscrites)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southern armyworm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Leucania convecta)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Where found</td>
<td>Thresholds</td>
<td>Control options</td>
</tr>
<tr>
<td>-------------</td>
<td>------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Corn aphids are usually found in the furled leaves of tillers. Oat aphids are usually found on the outside of tillers.</td>
<td>BYDV can be spread by low aphid numbers, especially by winged aphids flying into crops. Low numbers are difficult to detect. Assess your BYDV risk by looking at the Departments crop disease web site.</td>
<td>Chemical applications are recommended only if there is a high risk of aphid migrations. Recommended to apply sprays at 3 and 7 weeks post emergence.</td>
</tr>
<tr>
<td>Many native cockchafer are present in soil, under the roots of crops. Only Heteronyx is known to cause extensive crop damage.</td>
<td>3-5 Heteronyx grubs per shovel full of soil can cause crop damage especially if seedlings do not have extensive root systems.</td>
<td>Trials have shown that applications of chlorpyrifos as a seed dressing at sowing are able to control this pest. Higher seeding rates are another option if large numbers of cockchafers are found before sowing.</td>
</tr>
<tr>
<td>Feed at night, found in web lined tunnels in the ground usually with plant part protruding.</td>
<td>25 % of seedlings are damaged, at or just after emergence.</td>
<td>Grassy situations favour survival. If seeding post emergence, good control of weeds prior to seeding is recommended.</td>
</tr>
<tr>
<td>Feed at night and hide in soil during the day.</td>
<td>2 to 3 cutworm caterpillars per square metre.</td>
<td>Paddocks with good weed control for several weeks before sowing are less at risk.</td>
</tr>
<tr>
<td>Under debris, cloths of soil.</td>
<td>Consider control measures if holes are increasingly being found on leaves.</td>
<td>Reducing stubble residues in paddocks known to harbour earwigs will help to keep their numbers lower.</td>
</tr>
<tr>
<td>On weeds and seedlings.</td>
<td>Look for white bleaching on extensive areas of leaves and stress caused to plants.</td>
<td>Economical damage only occurs if these mites are present in very high numbers, especially if seeding into green bridge or if crop is moisture stressed. Under good growing conditions crops outgrow damage.</td>
</tr>
<tr>
<td>On weeds, soil and seedlings.</td>
<td>Look for bleaching on extensive areas of leaves and stress caused to plants.</td>
<td>Economical damage only occurs if these mites are present in very high numbers, especially if seeding into weedy paddocks or if crop is moisture stressed. Under good growing conditions crops often outgrow moderate damage.</td>
</tr>
<tr>
<td>On plants at night or hidden under clods, trash, or other objects during the day.</td>
<td>Black keeled slugs: 1-2 per m². Reticulated slugs: 5 per m².</td>
<td>Baits are best applied prior to seeding. Multiple applications are recommended.</td>
</tr>
<tr>
<td>On leaves, stems or on other nearby objects.</td>
<td>20 or more snails per m².</td>
<td>Other control measures such as weed control is required in addition to baiting to achieve long term control. Baits are best applied prior to seeding. Multiple applications are recommended.</td>
</tr>
<tr>
<td>Under the soil, Sometimes are difficult to find.</td>
<td>40 or more snails per m².</td>
<td>Seed treatments are the only recommendation for the control of this pest.</td>
</tr>
<tr>
<td>Colonies develop on the outside of tillers from the base upwards, on stems, nodes and back of mature leaves, starting any time between late tillering and grain filling.</td>
<td>If 50% or more of plants are infested with 15 or more aphids consider control measures.</td>
<td>Inspect numerous spots throughout paddock and check tillers at random. Aphid infestations can be controlled by parasitic wasps and other beneficials, consider applying soft chemical options to keep predators intact.</td>
</tr>
<tr>
<td>On plant or under leaf litter, but prefer rye grass.</td>
<td>Check crop regularly after flag leaf emergence, if maturing crops have 10 or more caterpillars per square metre control will be justified.</td>
<td>If large caterpillars are found when grain is ripening, apply chemical control. Effectiveness of spray applications is dependent on good penetration into the crop, which can be difficult to achieve in thick canopy crops.</td>
</tr>
<tr>
<td>Seedling pests</td>
<td>Aphids (for BYDV control)</td>
<td>Cutworm</td>
</tr>
<tr>
<td>----------------</td>
<td>--------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Seed dressing</td>
<td>125</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>250 or 500</td>
<td>700 - 900</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100 - 300</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 - 15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12 or 18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12 or 18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 - 15</td>
</tr>
</tbody>
</table>

Table 11. Registered insecticides for control of pests of Oats (Rates are given as mL/ha unless specified otherwise.)
The only option if these invertebrates are found in numbers that exceed allowable thresholds at grain receivals is to clean the grain.

Methods to decrease the number of vagrant insects in grain or hay:

• Swath cereals at a height of 150 mm. This allows the swath to form above the ground, supported by the stubble. If the swath is close to or on the ground, it is more likely that vagrant insects will be harvested with the grain or baled.

• Harvest swaths or bale oats for hay as soon as swaths are dry enough. The longer that swaths are left unharvested, the more vagrant invertebrates use them as a refuge, consequently increasing the number of insects that are harvested with the grain or baled for hay.

• Harvest swaths or bale for hay during the hottest part of the day. Most insects (apart from snails) are found under the swath during the hottest part of the day. However at night or under cool conditions, insects move out from under the swath and up onto the top of the swath, where they are more likely to be harvested with the grain or baled.

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• Harvest swaths or bale for hay during the hottest part of the day. Most insects (apart from snails) are found under the swath during the hottest part of the day. However at night or under cool conditions, insects move out from under the swath and up onto the top of the swath, where they are more likely to be harvested with the grain or baled.

• Pests such as snails are present throughout swaths. If snails are present, control measures need to be put in place at seeding to decrease snail numbers at harvest/baling.

Using insecticidal sprays under swaths is not effective

Some growers have used insecticidal sprays under swaths to deter insects from using swaths as a refuge. As the insects are not feeding on plant material under the swath, most insecticides are not effective. Trials have shown that spraying under swaths does not reduce the number of insects using the swath as a refuge. Additionally, no insecticides are registered for this use as it may lead to chemical contamination of the grain and rejection by national and international grain markets.

Direct harvested grain contains fewer vagrant insects

Trials have shown that directed harvested grain contains fewer vagrant insects but if grain is harvested at night, more vagrant insects can be found in the harvested grain.

If snails are present within paddocks, they can be found sheltering in the head of the crop at harvest, consequently becoming a grain contaminant. Controlling snails early in the season at crop germination will decrease numbers and decrease the need to clean grain for them.
Stored grain pests

Inspect stored grain for insects at least once a month in order to prevent severe infestations. Test for the presence of insects by checking samples of the stored grain with a grain sieve from top and bottom of the silo or pitfall traps in the headspace of the silo. Condensation in the headspace in autumn is a sure sign insects are creating the moisture somewhere in the silo. Grain insects reduce the quality of oats by reducing the germination of the grain, eating and contaminating feed intended for livestock and re-infesting machinery.

Important pests of stored oat grain are listed in Table 12.

Good hygiene of grain storage areas is strongly recommended. Other grain storage control includes:

- cooling grain with aeration
- fumigating sealed silos with phosphine generating tablets
- applying malathion insecticide but be aware Malathion resistance is widespread and it may not be effective
- treating grain by mixing with Dryacide.

When treating stored grain, growers need to be aware of the Maximum Residue Limits (MRL) for 60 chemicals that were introduced by Japanese buyers in 2006 and are likely to be introduced by some other buyers. To conform with the MRL, a grower must observe the withholding period listed on product packaging.

For further information on the control of stored oat grain pests can be found on the DAFWA website www.agric.wa.gov.au and the GRDC stored grain website www.storedgrain.com.au. Two publications that are essential reading are ‘Hygiene and structural treatments for grain storages- GRDC Fact Sheet Sept 2010 and ‘Fumigating with phosphine other fumigants and controlled atmospheres’ GRDC booklet 2011.

Acknowledgements

Much of the information in this section has come about from the research conducted by various Department of Agriculture and Food Entomologists that have worked on pests of Cereals over many years.

<table>
<thead>
<tr>
<th>Primary</th>
<th>Secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesser grain borer (Rhyzopertha dominica)</td>
<td>Rust-red flour beetle (Tribolium castaneum)</td>
</tr>
<tr>
<td>Granary weevil (Sitophilus granarius)</td>
<td>Confused flour beetle (Tribolium confusum)</td>
</tr>
<tr>
<td>Rice weevil (Sitophilus oryzae)</td>
<td>Saw-toothed grain beetle (Oryzaephilus surinamensis)</td>
</tr>
<tr>
<td>Angoumois grain moth (Sitotroga cerealella)</td>
<td>Flat grain beetle (Cryptolestes spp.)</td>
</tr>
<tr>
<td></td>
<td>Warehouse moth (Ephestia spp.)</td>
</tr>
<tr>
<td></td>
<td>Warehouse beetle (Trogoderma variabile)</td>
</tr>
</tbody>
</table>
**When to direct harvest grain**

If the crop ripens and dries evenly (to less than 12 per cent moisture), direct harvesting of the crop is the most economical way to harvest oats for grain. Harvest oats as soon as the crop is ripe to reduce grain shedding.

Non-dwarf and other varieties that are likely to shed or lodge should be harvested earlier than varieties less likely to shed or lodge.

To reduce harvesting delays, the grain can be direct harvested with the moisture content above 12 per cent and then placed under aeration or through a grain dryer to reduce the moisture content.

**When to swath grain**

If the oat crop is uneven in maturity or the climate does not allow for rapid drying of grain, growers can swath the crop. Swathing evenly ripens the crop and allows timelier harvesting. Swathing also helps minimise crop losses due to shedding and lodging.

Swathing can begin when the grain moisture content is below 35 per cent and the grain is at the medium dough stage, so it is hard but can still be dented with the thumbnail. Avoid swathing too early, when the grain is not fully developed, as this will result in small pinched grain. Also, do not swath when the ground is wet after rain.

Swathed grain should be harvested as soon as possible, ideally within 10 days of swathing. If swaths are left too long and are subjected to long periods of wetting (more than 25 mm of rain over four to eight days), grain may sprout and become stained and may become contaminated with field insects.

As a general rule crops that are likely to yield less than 2 t/ha should not be swathed.

**Storage of grain oats**

Correct storage of grain oats is particularly important when destined for human consumption. Before harvest, growers need to clean silos and surrounding areas and grain handling equipment. Grain stores need to be maintained and kept water tight. Water will cause moulding and sprouting of grain which is unacceptable if delivered.

The maximum moisture content at which oats can be safely stored is 12.5 per cent unless the temperature is reduced to below 15°C. Above the safe limit, fungi may develop and cause grain spoilage.

Stored grain needs to be protected from insect infestation. Infestations usually occur within three months, even in situations where risk is minimised by good hygiene.

Storing oats at a temperature below 20°C and a moisture content of less than 12.5 per cent should provide a shelf life of at least 12 months. Aeration is necessary for long-term storage of oats to maintain cool temperatures and reduce loss in grain quality from moisture, grain insects and mould.
Making quality hay

Raj Malik, Blakely Paynter, Kellie Winfield

The oaten hay market in Western Australia has developed significantly over the past 15 years. Export hay is sold to Japan, Korea, Taiwan and the Middle East. Hay is also used domestically by dairies, feedlots and the horse industry. Japan is our largest export customer, purchasing around 85% of Western Australian export hay produced from 2001 – 2006. Over 650,000 tonnes of export hay was produced by Western Australia in 2005/06.

The Japanese market is increasingly demanding high quality hay, particularly as Australian hay exporter’s work with Japanese buyers to show them why they should purchase our forage versus forage produced in another country. As a result of an increased focus on the quality of hay for the export market, interest in quality from the domestic market has also grown. The quality demand from the domestic market however does vary more from year to year depending on the availability of home produced forage and other feeds.

Choice of variety

For export hay, many export hay companies have preferred varieties they will receive whilst others have no preference. Check with your hay processor prior to planting for their list of preferred varieties. Often they will recommend growing an oat variety suited to your region.

Many common grain varieties (such as Carrolup, Wandering and Winjardie) are grown successfully for export and domestic hay. The National Oat Breeding Program has also recently released a range of specialist hay varieties including Brusher, Kangaroo, Mulgara, Wintaroo and Tungoo. These specialist varieties are best suited to growers who grow large areas of oats for hay or with specialised hay production systems. Older hay varieties such as Massif, Swan and Vasse are not widely accepted by export hay processors as their stems tend to be too thick.

Whilst variety will influence hay quality, cutting the hay at the correct time and growing it with appropriate management and inputs is the key to the successful production of high quality hay for both domestic and export use.

Quality parameters for hay

Good colour and aroma, sweet taste and fine texture are of major importance to export hay buyers. Hay processing companies in Western Australia also grade based on nutritional value. The number of grades and even grading systems differ between hay processors. Some companies have five grades, others have four and some grade based on a 100 points system. The emphasis on particular parameters is also different between processors and is subject to change depending on the season. Contact your hay processor when planning your program to determine whether their requirements suit you.

Table 13 provides a general guideline of the target quality required in oaten hay for receival into different grades. Unlike grain there is no common standard on which hay is received. Hay should have a maximum bale of moisture of 14 per cent at delivery to ensure that it does degrade or spoil during storage. Some export standards are as low as 12 per cent moisture. High moisture can also cause self combustion during storage.

Interest in oat hay for the dairy, feedlot and horse industries has increased in recent years due to the improvements in hay quality standards brought about by demand from the export market. In most cases Grade 2 hay will be sold by exporters to the domestic market, however annual quality requirements will depend on the price of alternative product used in livestock rations. In many cases the domestic market is loyal to suppliers who continually supply the right product throughout the year and can deliver on time.
Hay grown for export is required to meet a number of other crop hygiene requirements including:

**Annual ryegrass toxicity**
All export hay must be subjected to a compulsory sampling and testing protocol designed to ensure that there is a minimum risk of it being contaminated by the bacterium that causes annual ryegrass toxicity. Livestock deaths caused by annual ryegrass toxicity poisoning from Australian hay or straw exports in an importing country could devastate the Australian hay and straw export industry. If contamination by this bacterium is a potential problem, look to implement an annual ryegrass toxicity management program through the introduction of twist fungus or Safeguard A ryegrass.

**Weeds**
Export hay requires a nil presence of toxic plants and double gees. Most processors have a limit of 1% of broad leaf plants and 5% of other cereals/ryegrass/wild oats.

**Foreign/animal material**
There is a zero tolerance of foreign material including dirt, stones, sticks, insects, wool, wire and carcases in export hay. Paddock management requires contaminants to be removed prior to planting.

| Table 13. Typical target quality standards to meet different export hay requirements in Western Australia |
|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| Parameter                                       | Premium 1                                      | Premium 2                                      | Grade 1                                        | Grade 2                                        |
| Crude protein (CP) (%)                         | 4–10                                          | <4                                            | <4                                            | <4                                            |
| Water soluble carbohydrates (WSC) (%)           | ≥18–25                                        | ≥14–23                                        | ≥10–18                                        | ≥6–18                                         |
| Estimated metabolisable energy (estME) (MJ/kg DM) | <9.5                                         | <9.5                                         | <9.5                                         | <9.5                                         |
| Acid detergent fibre (ADF) (%)                  | ≥30–35                                        | ≥32–35                                        | ≥36–38                                        | ≥37–40                                        |
| Neutral detergent fibre (NDF) (%)               | ≤55                                           | ≤55–59                                        | ≤57–60                                        | ≤60–64                                        |
| In vitro digestibility (IVD) or digestible dry matter (DMD) (%) | ≥58–60                                        | ≥57–58                                        | ≥56–58                                        | ≥53–57                                        |
| Stem thickness (mm)                             | ≤6–12                                         | ≤8–12                                         | ≤9–12                                         | ≤10–12                                        |

CP is a measure of the total protein of the hay. It measures both true protein and non-protein sources of nitrogen. CP is used in developing rations.

WSC is a measure of plant sugars (sweetness) and is used as a guide to the palatability of the hay. Plant sugars are an important source of energy to the animal. Over 20% WSC is preferred.

EstME measures the amount of energy available per kg of hay dry matter. The available energy in the hay rises as digestibility and dry matter increase.

ADF is an estimate of the proportion of the hay not digestible to animals. As ADF increases, the hay is less digestible and food conversion efficiency decreases.

NDF is a measure of how much of the hay is plant cell wall. Plant cell wall provides ‘bulk’ rather than nutrients to the diet. Whilst some ‘bulk’ is required for rumen functionality in ruminants, high NDF can limit feed intake.

IVD and DMD are measures of the proportion of the diet that an animal is able to digest and absorb. If hay is 66% digestible, an animal fed 1000 g of hay would digest 660 g and produce 340 g of manure. Animals fed hay with a low IVD or DMD can lose condition regardless of how much feed they intake.

Hay with fine, stems is generally preferred, as it contains less fibre in the cell walls.

**Disease**
A maximum of 10% affected leaves is allowed by most processors. Also check withholding periods on labels of all fungicides being considered for use. Do not apply fungicide if the likely cutting date is within a withholding period. For best control, plant disease resistant varieties.

**Chemical residue**
Export markets (particularly Japan) expect a clean and green product from Australia and thus limited use of chemicals. In 2006 Japan introduced regulations to enforce the safety of imported animal feeds which included the establishment of MRL’s for 60 chemicals in
feeds including hay and grains such as wheat, barley and oats. Speak to your exporter about their requirements for documenting chemical use.

**Nitrates**

The desired nitrate level in hay is < 500 mg/kg. Under infrequently experienced conditions oat plants, like other cereals, can accumulate much greater quantities of nitrates than this, and these are conserved in the process of hay making. In these situations the hay may be toxic, and in some cases the toxic potential can be enhanced if the hay is dampened by rain.

Export hay has a strong emphasis on water soluble carbohydrates, particularly for the Japanese market. This is mainly driven by the Japanese buyers who physically taste the hay and use this concept to sell the hay to dairy farmers. The reasoning is that hay, which is high in water soluble carbohydrates is usually high in digestible dry matter and low in fibre and therefore more palatable, resulting in higher intake and higher production. Hay exported to Japan must also be of excellent green colour, texture, smell and taste. These characteristics are also generally sought by the domestic market, however, there appears to be little evidence that animals prefer hay due to its colour but aroma has been found to have an influence for some animals.

Domestic hay quality has an emphasis on nutritional value, particularly crude protein and metabolisable energy. The desired level for crude protein is > 8% and metabolisable energy is > 9.0 MJ/kg dry matter. Many of the hygiene requirements for export hay are also relevant to the production and marketing of hay for domestic use.

**Hay cutting time**

There is always a conflict of interest between growers and exporters. Growers are always looking for higher yields while the exporters seek higher quality.

The optimum cutting time recommended by most processors is at the watery-ripe stage (Z71) or earlier. When the top florets are squeezed at this stage, a clear watery liquid appears (Figure 27). If the liquid is white, then the optimum stage of cutting has already occurred. Test the crop at several places in the paddock. If more than half the paddock is at the watery ripe stage, this is the perfect time to cut.

Cutting hay a week later than the watery ripe stage reduces the quality but it is still within the acceptable range of export standards. This means that there is a five- to seven-day window of opportunity before quality starts to fall below premium levels and starts affecting returns. This gives growers some flexibility to accommodate contracting and rainfall issues.

Rainfall events of 10 mm or over can drastically reduce the quality of cut hay. Therefore, it is important to consider delaying cutting if a significant rainfall event is forecast. Hay quality is most at risk when exposed to rainfall events between cutting and baling, resulting in fading of colour, moulding and decline in nutritive value.

Risk can be minimised if more than one variety is planted. The cutting date will vary with each variety, due to the different maturing times. Just remember: 'You can’t manage what you don’t observe and don’t measure'.

Hay cut before the watery ripe stage has the highest quality, but the penalty to the
grower is lower hay yields. Early cut hay usually has thinner stems, more crude protein, slightly lower fibre (ADF and NDF) levels, is more digestible and has higher metabolisable energy than hay cut after watery ripe.

Whilst cutting hay after the watery ripe stage may result in increased hay yield, the hay is of lower quality. Late cutting (14 days or more after the water ripe stage) usually results in hay with a poorer colour, less crude protein, lower digestibility, and lower metabolisable energy (Table 14). The impact of late cutting on stem fibre (ADF and NDF) levels and water soluble carbohydrates is greatest in seasons where there is a dry finish (for example compare the data from the dry season of 2006 with that of the wetter season on 2005 in Table 14).

### Table 14. Change in hay quality when cut was delayed by two weeks from watery ripe stage (data is an average of six varieties)

<table>
<thead>
<tr>
<th>Stage (May–October rainfall)</th>
<th>2005 (362 mm)</th>
<th>2006 (186 mm)</th>
<th>LSD (p=0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z71 + 14 days</td>
<td>Z71 + 14 days</td>
<td>Z71 + 14 days</td>
<td></td>
</tr>
<tr>
<td>Stem thickness (mm)</td>
<td>5.7</td>
<td>5.6</td>
<td>5.7</td>
</tr>
<tr>
<td>Leaf greenness (SPAD)</td>
<td>50.2</td>
<td>40.0</td>
<td>48.6</td>
</tr>
<tr>
<td>Crude protein (%)</td>
<td>4.1</td>
<td>2.4</td>
<td>6.6</td>
</tr>
<tr>
<td>ADF (%)</td>
<td>28.2</td>
<td>27.3</td>
<td>28.3</td>
</tr>
<tr>
<td>NDF (%)</td>
<td>47.7</td>
<td>45.2</td>
<td>47.5</td>
</tr>
<tr>
<td>IVD (%)</td>
<td>58.9</td>
<td>57.6</td>
<td>63.2</td>
</tr>
<tr>
<td>estME (MJ/kg DM)</td>
<td>8.4</td>
<td>8.1</td>
<td>9.0</td>
</tr>
<tr>
<td>WSC (%)</td>
<td>35.5</td>
<td>35.1</td>
<td>24.9</td>
</tr>
</tbody>
</table>

Figure 27. The watery ripe stage (left) is reached just before milk development (right). When the grain is squeezed a watery green/white liquid will come out, opposed to a milky white liquid (right). (Photo: Kellie Winfield DAFWA)

**Impact of variety on cutting date**

Table 15 groups different oat varieties into a range of maturity classes, based on their duration to watery ripe when sown between late May to early June in the region between Northam and Katanning. Groups are based on expected differences in maturity relative to Carrolup and are calculated from flowering date trials which were monitored three times per week.

Large differences in duration to watery ripe were noted among oat varieties. The difference between the earliest (Yilgarn) and latest (Massif) was over 30 days. In the hay varieties, Brusher ♂ generally reached the watery ripe stage first, followed by Marloo, Swan, Winjardie and Kangaroo ♂ and finally by Wintaroo ♂. Brusher ♂ was ready for cutting
Making quality hay

Impact of sowing date on cutting date

The maturity group ranking is based on the flowering date of oats when sown in late May and early June. Figure 28 shows the change in duration to watery ripe (optimum cutting stage) as the date of seeding is delayed for eight varieties representing different maturity groups.

Table 15. Maturity groups of 24 oat varieties grown in Western Australia based on the duration to reach watery ripe when sown in late May to early June in the region between Northam and Katanning

<table>
<thead>
<tr>
<th>Maturity group (days relative to Carrolup)</th>
<th>Code</th>
<th>Variety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early spring -3 to -7 days</td>
<td>E</td>
<td>Coomallo, Hotham, Mitika (\text{h}), Yilgarn, Pallinup, Possum (\text{h}), Wandering (\text{h})</td>
</tr>
<tr>
<td>Medium spring -2 to +2 days</td>
<td>M</td>
<td>Brusher (\text{h}), Carrolup, Euro, Kojonup (\text{h}), Mortlock, Toodyay, Quoll (\text{h})</td>
</tr>
<tr>
<td>Medium to late spring +3 to +7 days</td>
<td>M–L</td>
<td>Dalyup, Kangaroo (\text{h}), Marloo, Potoroo, Swan, Winjardie</td>
</tr>
<tr>
<td>Late spring +8 to +12 days</td>
<td>L</td>
<td>Wintaroo (\text{h}), Needilup (\text{h})</td>
</tr>
<tr>
<td>Very late spring +18 to +22 days</td>
<td>VL</td>
<td>Vasse</td>
</tr>
<tr>
<td>Extremely late spring &gt; +28 days</td>
<td>EL</td>
<td>Massif</td>
</tr>
</tbody>
</table>

As oat varieties modify their flowering date in response to changes in daylength (due to location) and temperature (due to season and sowing date), some varieties are more sensitive to particular sowing dates than others.

Needilup, Possum \(\text{h}\), Swan and Winjardie are more sensitive to daylength than other varieties. They are able to contract the period from sowing to watery ripe if seeding is delayed into late June and July and lengthen the period from sowing to watery ripe if seeding begins in late April.

This means that these varieties may flower at a different time relative to other varieties in their same maturity group when sown in early May or late June. For example, Winjardie
Making quality hay

Cut hay crops at the watery ripe stage (Z71) as this is the best compromise between hay yield and hay quality.

sown in late April may reach the watery ripe stage some 14 days later than Carrolup. When Winjardie is sown in late May, it reaches the watery ripe stage 7 days later than Carrolup. A late June sowing will reach watery ripe stage only 3 days later than Carrolup. Most varieties follow the patterns exhibited by the variety representing their maturity group in Table 15 and Figure 28.

It should be noted that a three-week delay in sowing date results in a delay of about 7 to 10 days in cutting date for most varieties sown in May and June (Figure 28). For example, we would expect Carrolup to be ready for hay cutting (watery ripe) at Katanning about 11 October when sown on 28 May and about 20 October if seeding was delayed three weeks until 18 June.

When choosing varieties to sow it is important to take into account their maturity group and likely differences in duration to reach watery ripe. Depending on which varieties are chosen, sow each variety at the appropriate time to spread the risk (so they are ready for cutting at staggered times).

**Impact of season on cutting date**

Average daily temperature influences the duration to watery ripe. In seasons or locations with a higher than average temperature during winter, a shorter duration to watery ripe (up to one week earlier than the predicted date) will result. Seasons with a lower than average temperature may result in a later duration to watery ripe (up to one week later than the predicted date).

**Impact of location on cutting date**

Flowering date trials conducted at Katanning and Northam show large differences in the predicted date at which oat varieties will reach the watery ripe stage due to location. This is due to differences in daylength and temperature between locations. During winter, for example, Katanning has slightly shorter days and slightly lower average temperatures. It takes an oat crop sown at Katanning about 14 days longer to reach the watery ripe stage than an oat crop sown on the same day in May at Northam. When seeding is delayed to June, the Katanning crop will reach watery ripe about 10 days later than an oat crop sown at Northam on the same day.

**Hay cutting height**

Cutting height, as a rule of thumb, is 15 cm (the height of a soft drink can). High yielding crops and lodged crops may need to be cut slightly higher to ensure the weight of the windrow is supported off the ground. Cutting higher may reduce the yield but has a marked influence on quality. Cutting too low will compromise the drying process and the hay quality as the cut stems are too thick and discoloured, with a higher fibre content and lower digestibility. There is also a greater risk of picking up more dirt while raking.
**Baling**

The moisture content of baled hay is critical and baling high moisture hay should be avoided at all costs. Hay baled at over 18 per cent moisture is at risk of developing mould in the bale. There is also a risk of spontaneous combustion occurring when stored.

Export markets prefer baled hay with moisture content of less than 14 per cent; some exporter standards are as low as 12 per cent moisture. At these low moistures the risk of spontaneous combustion during storage is minimised. There is also a lower risk of condensation dropping off the container roof onto the hay during transit, creating wet patches and encouraging mould formation. High density bales do not dry readily because of low air exchange rates and the insulating qualities of hay. Bales of 18 per cent moisture may take many months to dry to an acceptable moisture content.

Judging exact moisture for baling is not easy, but two tests are as follows:

- Twist a few stems from the windrow and examine the joints for a show of moisture. If moisture is evident, the crop is too moist.
- Use the bark test. Scratch the stem of the plant with a fingernail. The outer layer will lift if it is too moist, but will not if the crop is dry enough.

Particular attention must be paid to raking. A poor job will pick up dirt and stones which will cause the hay to be downgraded.

**Storing hay**

It is important to have hay in storage as soon as possible after baling to prevent any damage from weather exposure. Many hay exporters will require growers to store hay for long periods of time. Appropriate storage will prevent weather damage (from sun, rain and wind). Sheds should have at least three walls (with the opening facing away from prevailing weather). If floors are not concrete, heavy duty black plastic should be used to prevent moisture rising into the bales. Moisture affected bales will be rejected for export. Shed design should provide adequate air flow throughout the stack to dissipate any heated hay which can lead to spontaneous combustion. A bonus is often paid to growers who are able to store export hay on farm. Domestic hay will also benefit from being stored under the same criteria as export hay.

The temperature of a stack can be checked with a temperature probe, crow bar or other piece of solid steel. Leave the bar in the stack for approximately 2 hours. If the bar is only just tolerable to touch after being removed from the hay stack, this indicates that bale temperatures are greater than 60°C. If the temperature continues to rise, the stack needs to be pulled apart. Tubular steel should not be used as this may allow air into the stack and create an environment for combustion to occur.

Water and fire fighting equipment should be on hand to prevent shed fires. Bales that have reached a high temperature may ignite as they are pulled apart and introduced to a more available oxygen supply.

The exact cause of spontaneous fires in hay stacks is not fully understood. In most cases it generally takes five to ten weeks for conditions to be right for combustion to occur, although it can occur in as few seven days under ideal conditions. For a fire to occur there is usually both respiration heating and biological heating (primary source) and then exothermic heating (secondary source).
Further reading


Micic, S, Henry, K & Horne, P 2007. Identification and control of pest slugs and snails for broadacre crops in Western Australia Bulletin 4713, Department of Agriculture and Food, Western Australia, South Perth.


Vanstone V and Lewis J (2009). Plant parasitic nematodes fact sheet, Southern and Western region, Managing cereal cyst and root lesion nematodes. GRDC.


Further reading


**Important websites**
Australian Fodder Industry Association (AFIA): <www.afia.org.au>
Department of Agriculture, Western Australia, ‘Oat Production in Western Australia’ <www.agric.wa.gov.au>
GRDC Stored Grain Website www.storedgrain.com.au
Appendix 1. Zadoks growth scale

(Compiled from *The Wheat Book*, Anderson & Garlinge 2000)

The Zadoks decimal growth scale is based on 10 cereal growth stages.

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0: **Germination**
- 00: Dry seed
- 01: Start of water absorption
- 03: Seed fully swollen
- 05: First root emerged from seed
- 07: Coleoptile emerged from seed
- 09: First green leaf just at tip of coleoptile

1: **Seedling growth**
Count leaves on main stem only. Fully emerged = ligule visible. Subdivide the score by rating the emergence of the youngest leaf in tenths. For example, 12.4 = two emerged leaves plus the youngest leaf at 4/10 emerged.
- 10: First leaf through coleoptile
- 11: First leaf emerged
- 12: 2 leaves emerged
- 13: 3 leaves emerged
- 14: 4 leaves emerged
- 15: 5 leaves emerged
- 16: 6 leaves emerged
- 17: 7 leaves emerged
- 18: 8 leaves emerged
- 19: 9 or more leaves emerged

2: **Tillering**
Count visible tillers on main stem; that is, the number of side shoots with a leaf blade merging between a leaf sheath and the main stem.
- 20: Main stem only
- 21: Main stem and 1 tiller
- 22: Main stem and 2 tillers
- 23: Main stem and 3 tillers
- 24: Main stem and 4 tillers
- 25: Main stem and 5 tillers
- 26: Main stem and 6 tillers
- 27: Main stem and 7 tillers
- 28: Main stem and 8 tillers
- 29: Main stem and 9 or more tillers

3: **Stem elongation**
Generally count swollen nodes that can be felt on the main stem. Report if dissection is used.
- 30: Pseudostem (youngest leaf sheath erection)
- 31: First node detectable
- 32: Second node detectable
- 33: Third node detectable
- 34: Fourth node detectable
- 35: Fifth node detectable
- 36: Sixth node detectable
- 37: Flag leaf just visible
- 38: Flag leaf ligule just visible

4: **Booting**
Score the appearance of the sheath of the flag leaf.
- 41: Flag leaf sheath extending
- 43: Boots just visible swollen
- 45: Boots swollen
- 47: Flag leaf sheath opening
- 49: First awns visible

5: **Ear emergence from boot**
- 51: Tip of ear just visible
- 53: Ear 1/4 emerged
- 55: Ear 1/2 emerged
- 57: Ear 3/4 emerged
- 59: Ear emergence complete

6: **Anthesis (flowering)**
Generally scored by noting the presence of emerged anthers.
- 61: Beginning of anthesis (few anthers at middle of ear)
- 65: Anthesis half-way (anthers occurring half way to tip and base of ear)
- 69: Anthesis complete

7: **Milk development**
Score starch development in the watery kernel.
- 71: Kernel water ripe (no starch)
- 73: Early milk
- 75: Medium milk
- 77: Late milk

8: **Dough development**
Kernel no longer watery but still soft and dough-like
- 83: Early dough
- 85: Soft dough
- 87: Hard dough

9: **Ripening**
- 91: Grain hard, difficult to divide
- 92: Grain hard, not dented by thumbnail
- 93: Grain loosening in daytime
- 94: Over-ripe straw dead and collapsing
- 95: Seed dormant
- 96: Viable seed giving 50% germination
- 97: Seed not dormant
- 98: Secondary dormancy induced
- 99: Secondary dormancy lost
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