The Barley book

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The Barley Book

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DEPARTMENT OF AGRICULTURE
WESTERN AUSTRALIA

The Grain Pool of Western Australia

GRDC
Grains Research & Development Corporation
The Barley Book

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THE GRAIN POOL
OF W.A.

GRDC
Grains Research & Development Corporation
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FOREWORD

The Grain Pool of Western Australia is proud to join the Grains Research and Development Corporation as co-sponsor of the first comprehensive book on barley production and management published in Australia.

The book will be an invaluable aid to barley growers, giving them the latest facts on barley production, agronomy and marketing. In this age of rapidly changing technology and increasing costs, growers need to be aware of the latest advances in production and management to ensure maximum profitability.

The Western Australian barley industry is presently in good shape and initiatives such as the continued focus on quality and end-user service are being undertaken to ensure this continues in the future.

Essential to this success will be the need for improved malting varieties. The Barley Fast Track Breeding Program is showing results, having provided funding for the development of several new lines of feed and malting barley due for release in 1996 and 1997.

The Grain Pool is liaising with maltsters overseas and domestically to ensure new and existing Western Australian barley varieties meet their quality standards.

New markets are being opened up with the first export shipment of Franklin barley from Australia being sent to China at the end of the 1995/96 season by the Grain Pool.

In the long-term, I believe the Western Australian barley industry is in a prime position to take advantage of the rapidly growing Asian markets for barley and barley products. Growers should look to the future with optimism as new and expanding markets will guarantee the long-term viability of growing barley as part of an economically sound farming business.

R.I. Sewell
Chairman of Directors
The Grain Pool of Western Australia
Introduction

Kevin Swan

General Manager, The Grain Pool of Western Australia

Barley is a widely grown and highly adaptable crop which on a worldwide basis ranks fourth in importance behind wheat, maize and rice. Because of its early maturity barley is commonly grown in semi-arid regions where wheat and rye cannot mature before soil moisture supplies are exhausted. Later maturing winter barleys can survive a period beneath snow but are generally not as winter-hardy as winter wheat and rye varieties.

In Western Australia barley is grown as a crop for late sowing in the drier wheatbelt regions and as a high yielding crop in the higher rainfall areas where later maturing barley varieties are better able to tolerate leaf and root diseases than wheat.

Barley as a crop

Barley was one of the first crops to be domesticated. Archaeological diggings and carbon dating suggest that barley was an important food crop as early as 8000 BC in the Mediterranean region. When salinity affected the irrigated lands of southern Mesopotamia, and wheat production started to decline, barley increased in importance and by 1800 BC was the dominant crop because of its salt tolerance. Wheat was not accepted as the preferred grain for breadmaking until around the first century AD.

Uses

Today barley is mainly used as an animal food, especially in the rapidly expanding feedlot industry. The second most important use is in the production of malt, most of which is used to brew beer, and the remainder in the distillation of malt whisky and as human food. The use of unmalting barley grain as human food plays only a minor role, except in regions of the world where wheat grows poorly due to altitude, salinity or lack of rainfall. About 5 per cent of the world barley crop is retained for use as seed.

Barley production in Western Australia - the early years

Before 1920 the annual production of barley in Western Australia was less than 1000 tonnes per year. European varieties were sown in small areas with mixed results. These early varieties were generally late maturing with extremely weak straw and farmers preferred to grow wheat varieties which were far better adapted to local conditions. Before 1920 both malt and malting barley were imported, initially from overseas and eventually from the eastern States.
In 1923, a malting quality variety (Prior) with early maturity and improved straw strength was introduced from the eastern States to coincide with the establishment of a commercial malthouse by Union Maltings.

In the 1930s, in competition with California, an export trade to Britain was developed based on the supply of the six-row barley variety Atlas. At the time British maltsters preferred the bright grain of low moisture content supplied from California; Western Australia was considered the ideal climate to produce a similar product. In this period the supply of the two-row variety Prior to local maltsters was insufficient to meet demand and imports were made from the eastern States until monetary incentives were offered to growers in certain areas by the local trade. This system proved so popular that by 1939 the area of incentive was restricted. In the post-war period Britain reduced its imports of malting barley as its local supply increased. The export of barley for feed increased in this period and Atlas was replaced in 1957 by the six-row feed variety Beecher.

**The Grain Pool of Western Australia**

The Grain Pool of Western Australia has been responsible for marketing the State's barley crop since 1952. Over the years many export markets have been developed and barley is now exported to over 17 countries.

The Grain Pool is an important part of the State's economy. It is grower controlled through an elected Board of Directors and the Producers Council who represent all growers.

The Grain Pool has statutory marketing rights over all lupins, barley and canola produced in Western Australia. It also trades in other grains and coarse seeds such as oats, chickpeas, field peas, faba beans, triticale and albus lupins.

**Marketing the crop**

The Grain Pool has sold Western Australian barley to over 25 countries since it gained statutory marketing rights for the grain. The major export destinations have changed over the years with Asia rapidly becoming the dominant importer of malting barley.

In the 1980s, the majority of malting barley was exported to the South American and European markets. This has changed markedly in the 1990s as the Asian economies have begun to grow at unprecedented rates and are willing to pay a premium for the Western Australian grown product.

In years of normal supply China, Japan, Turkey and Taiwan are the major export buyers of Western Australian malting barley. South American countries have access to cheap US, Canadian and European barley and buy Western Australian malting barley in times of oversupply.

In a recent market development the Grain Pool exported the first shipment of Franklin barley to China. This is the first step in developing a market niche for Franklin barley in direct competition with Canadian and European grown plump varieties. It gives Franklin producers a small foothold in a market with huge potential.

Feed barley markets have remained fairly static over the years, with Japan and Taiwan consistently being the major buyers followed by various Middle Eastern countries.
The future

The future of the Western Australian barley industry is tied to the rapidly developing Asian economies. Given the State's geographic location and barley production capabilities, barley growers should be major beneficiaries of this growth.

Japan and Taiwan will continue to be significant buyers of feed barley as their feedlotting operations expand to cater for increased beef demand. Domestic feed barley markets will also expand in coming years with feedlotting of beef cattle becoming more prevalent in this State and on the east coast. If current feedlotting growth trends continue, Western Australia may soon be the only major exporter of feed barley, with the majority of east coast production being consumed on the domestic market.

The future for malting barley is very promising given the rapid rate of growth in the demand for beer in Asia. This is in contrast with brewing downturns being experienced in some Western countries.

The Korean and Taiwanese markets are also set for major growth as taxation barriers to beer production are removed and these countries continue to strengthen economically.

Market development

The introduction of new brewing technology and continued technical support to Asia by Western Australian maltsters and the Grain Pool of Western Australia will be paramount in developing markets for malting barley. Existing breweries in the Asian region are having trouble keeping up with rapidly increasing demand. By helping Asian markets develop their brewing technology Western Australia will accelerate the growth in the region and ensure the Grain Pool is in a strong position to take advantage of the situation.

The future success of Western Australian malting barley in Asia relies heavily on maintaining present quality standards and introducing superior varieties of malting barley to these markets. The industry's barley Fast Track Breeding Program is aimed at providing growers with new improved barley varieties three to four years earlier than before. This will ensure Western Australian growers and marketers can supply the same, if not better, quality barley than competitors in the future.

Competition

Canada, Australia's major competitor on world barley markets, ships some 4.2 million tonnes abroad annually from a total production of approximately 11.9 million tonnes.

The major differences between Canadian and Western Australian barley production are the proportions exported and the way in which barley is used.

Canada consumes about 7.7 million tonnes of barley per year, mainly in feed rations, and exports about 35 per cent of total production. Of Canada's total barley production about 5 per cent is exported for malting or as malt. About 4 per cent of total...
production is used locally for distilling and malting.

Western Australia produces about 1 million tonnes of barley each year and exports around 95 per cent of this production. About 60 per cent of Western Australia's total barley production is used for malting with about 49 per cent of this being exported.

Conclusions to be drawn from these figures are that Western Australian barley is of a much higher quality standard than Canada's and that the Western Australian barley industry is more export oriented. This puts the State in an excellent position to compete with Canada for the booming Asian barley markets. Asian brewers will be looking to source quality malting barley from an exporter with a track record.

Through the Grain Pool, Western Australian barley growers will have the opportunity to access these premium paying markets. The only question remaining to be asked is, "can we supply enough quality malting barley in the future to satisfy the rapidly growing Asian demand?"

---

**The importance of grain quality in marketing the crop**

Western Australian barley enjoys a reputation as the prime malting product available on world markets. This puts Western Australian growers and the Grain Pool in a position to capitalise on future growth in barley demand, particularly in the Asian region.

This reputation is a result of three factors:

- bright visual appearance of the grain;
- low moisture content;
- consistent quality standards.

These factors and others are outlined below and are the major grain quality factors that affect the marketing of Western Australian barley.

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**Malting barley quality**

Western Australia, in comparison with barley growing areas in other parts of the world, has a climate conducive to the production of bright coloured barley.

Maltsters and brewers require bright coloured barley for the production of high quality malt and brewed products. Poorly coloured or stained barley will only be bought as a last resort as it presents specific problems to end users. For example, weather stained barley will sometimes carry its poor colour through to the end product. Barley with fungal staining can cause more severe problems such as a low level of malt extract in the malt house, poor flavour, gushing or overfoaming and reduced shelf life of beer produced from it.

Low moisture content is also important in malting barley, particularly when it is being stored for any length of time. Moisture levels above 12.5 per cent in stored barley will promote fungal growth and cause problems.
Consistent quality is important when marketing malting barley. The Grain Pool has a reputation for supplying barley with consistent quality specifications. This is mainly as a result of standards set by the Grain Pool and applied at Co-operative Bulk Handling during harvest. International malting barley buyers know that when sourcing barley from Western Australia, receival standards have been applied consistently across all deliveries. This ensures protein, screening, moisture levels, and other quality factors are kept at acceptable levels. Quality is a major problem for buyers of Canadian malting barley where receival standards are significantly more lax than in Western Australia.

Protein is arguably the most important factor when marketing malting barley. The ideal protein range is between 9.5 and 11.0 per cent. Barley with protein levels either side of this range will cause quality problems in the end product and produce less malt extract per tonne.

Other quality aspects considered by malt barley buyers include grain plumpness and weight. The heavier the grain, the more malt per tonne will be extracted. Malting barley must also be of the one variety as each variety of barley responds differently in the malthouse. Screenings and skinned grains must also be kept to a minimum as these will cause uneven germination during steeping.

Feed barley quality

The two most important factors considered by feed barley buyers are grain brightness and moisture content.

Grain brightness is important as many purchasers of feed barley on-sell to other end users. Primary buyers of feed barley will therefore attempt to purchase the brightest grain possible to increase their chances of on-selling at a premium price.

Moisture levels are important for storage reasons. Feed barley is often stored for long periods and excessively moist barley will decline in quality due to the growth of microflora during storage.

Protein is a minor consideration for buyers of feed barley as it is bought primarily for its energy content rather than as a protein source. As long as protein is at an acceptable level (8 per cent and up) it is of little consequence.
1. GROWTH AND DEVELOPMENT OF THE BARLEY PLANT

Kevin Young

Esperance Agricultural Centre

To understand the reasons for success or failure of a barley crop requires a basic knowledge of its growth and development.

Structure of the grain

A simplified structure of the barley grain is shown in the sketch. The major components are the embryo which is the young plant, and close inspection shows the coleoptile, three to four embryonic leaves and rootlets. The endosperm is the store of starch and so constitutes the seed reserve or, in the malting process, the starch from which fermentable sugars (or malt extract) are formed. The husk is made up of the palea and lemma and in most cases adheres to the endosperm. The exception is naked or hulless barley varieties such as Morrell.

Top photo - Germinating barley grain showing seedling roots and coleoptile. Above - Close-up of coleoptile protecting the first leaf

When the coleoptile reaches the surface its growth ceases and the tip of the first leaf emerges. If seed is sown deeper than the optimum depth an internode forms between the roots and the growing point or shoot apex (which is concealed by leaves). The formation of an internode ensures that the shoot apex is situated just below the soil surface. If the seed is placed so deep that the coleoptile is unable to reach the surface, the emerging leaf will have distinctive yellow bands. Deeply sown plants lack early vigour and tillering is delayed.

Germination and emergence

At germination the seedling roots emerge first, followed shortly after by the coleoptile which is a leaf-like structure that protects the first true leaf as it pushes up to the soil surface.
temperature calculated as the average of the maximum and minimum temperature. If, for instance, the daily maximum was 20°C and the minimum 10°C, then the heatsum for that day would be 15°C day. Six such days would give a total of 90°C day, so one leaf would have emerged under those conditions.

**Tiller formation**

Tillers arise from buds situated at the base of leaves. After the third leaf on the main stem is fully unrolled the first tiller emerges from the base of the oldest leaf. Tillers that emerge from the base of main stem leaves are the primary tillers and these make the largest contribution to yield after the main stem itself.

When primary tillers reach three leaves they also give rise to secondary tillers. Similarly, secondary tillers may go on to develop and give rise to tertiary tillers, although rarely do either contribute to grain yield, with the exception of very high yielding crops. As spent tillers die off, most of the nutrients contained in them are recycled to support the fertile tillers. Under conditions of moisture or nutrient deficiency the tiller buds remain dormant. Plants that are drought stressed or nitrogen deficient characteristically produce very few tillers.

**Leaf formation**

Following plant emergence, the shoot apex continues producing leaves until it undergoes a change to the reproductive phase when the ear is formed. The total number of leaves produced on the main stem by the shoot apex varies from 5 to 15 or more. The final leaf number is determined by the variety's response to daylength, temperature and the basic vegetative period (BVP). Leaves continue to emerge even after the shoot apex has started to initiate the ear.

The rate of leaf emergence is directly related to temperature. For the barley variety Stirling, one leaf emerges on the main stem for each 90°C day (this is a measure of thermal time and is a sum of the daily mean temperatures).
Ear formation

To detect the switch from leaf to ear formation, leaves must be stripped away and the shoot apex inspected under a microscope. The first sign of ear initiation is the presence of double ridges on the mounds on either side of the apical dome. The floral structure differentiates rapidly until finally the awn primordia are formed. It is possible to predict floral initiation for a given variety and planting date. Stirling barley, for example, sown in May or June will reach floral initiation shortly after four leaves have emerged on the main stem, and initiated awn primordia by the time eight main stem leaves have appeared. This relationship between leaf number and floral initiation changes with later sowings, when increased daylength speeds up the rate of development.

During stem elongation the barley ear or spike grows rapidly. The spike of a typical two-row barley has two rows of fertile florets and four rows of infertile florets. In a six-row barley, all six rows of florets are fertile.

Stem elongation and growth of the ear

Plants start to run up to head or "stem elongation" during the final stages of floral initiation. By the time awn primordia are initiated the main stem is rapidly elongating. Elongation is the growth of the stem sections between the nodes (internodes). Each node gives rise to a leaf made up of the sheath, which wraps around the stem, and blade. The number of internodes is usually five or six.

Generally the later a plant starts stem elongation, the more spikelets will be set in an ear. Poor growing conditions may affect the number of spikelets that survive, with death occurring from the tip back.

Fertilisation and grain growth

The commonly grown two-rowed varieties are self-fertilising. After the last leaf (flag leaf) has emerged the ear grows in the flag leaf sheath. At about the time of ear emergence, pollen is matured and released inside each floret before the anthers appear on the outside of the ear. Barley differs from wheat in that anthesis generally occurs close to ear emergence, while in wheat it is often 10 days after ear emergence.
After fertilisation there is a period of rapid cell division and in this time the potential size of the grain is determined. This is followed by a period in which starches are deposited in the endosperm; at first the grain contents are milky and then dough-like. When growth of the grain ceases it loses moisture rapidly and is eventually ready for harvest. The duration of the grain filling period is generally controlled by moisture availability and temperature. The rate and duration of grain filling varies greatly between varieties.

**The Zadok growth scale**

The Zadok growth scale is becoming the standard method for describing the development stage of cereals in Western Australia. Knowledge of the growth scale is important for the correct timing of fertilisers, herbicides, fungicides and insecticides. If you have followed the sections on growth and development, the Zadok growth scale is straightforward.

---

**Stage Z11, 11**
- First leaf (L1) unfolded on mainstem

**Stage Z13, 21**
- Third leaf (L3) unfolded with first primary tiller (T1) emerging from its base

**Stage Z15, 22**
- Fifth leaf (L5) on mainstem unfolded.

**Stage Z17, 27**
- The seventh leaf on the mainstem has now unfolded, there are five primary tillers and two secondary tillers emerged. The secondary tiller (T1.1) has emerged at the base of tiller 1.

**NB:** Mainstem leaves (in black) emerge from alternate sides. Tillers (white) emerge from the base of each mainstem leaf, commencing when three leaves have unfolded.
Table 1. The complete Zadok’s growth scale

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
</table>
| 0     | Germination  
00: Dry seed  
01: Start of water absorption  
03: Seed fully swollen  
05: First root emerged from seed  
07: Coleoptile (sheath around shoot) 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.  
Sub-divide the score by rating the emergence of the youngest leaf in tenths, for example, 12.4 = two emerged leaves plus youngest 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, side shoots with a leaf blade emerging between a leaf sheath and the main stem.  
20: Main shoot only  
21: Main shoot and 1 tiller  
22: Main shoot and 2 tillers  
23: Main shoot and 3 tillers  
24: Main shoot and 4 tillers  
25: Main shoot and 5 tillers  
26: Main shoot and 6 tillers  
27: Main shoot and 7 tillers  
28: Main shoot and 8 tillers  
29: Main shoot and 9 or more tillers |
| 3     | Stem elongation  
Generally count swollen nodes or ‘joints’ that can be felt on the main stem.  
Report as ‘detected by dissection’ if stages 31 or 32 are determined by dissecting the stem.  
30: Youngest leaf sheath erect  
31: First node detectable  
32: 2nd node detectable  
33: 3rd node detectable  
34: 4th node detectable  
35: 5th node detectable  
36: 6th node detectable  
37: Flag leaf just visible  
39: Flag leaf ligule just visible |
| 4     | Booting  
Score the appearance of the sheath of the flag leaf.  
40: Flag leaf sheath extending  
41: Flag leaf sheath extending  
42: Boots just visible swollen  
43: Boots swollen  
47: Flag leaf sheath opening  
49: First awns visible |
| 5     | Ear or panicle emergence (from boot)  
50: Tip of ear just visible  
51: Ear 1/4 emerged  
55: Ear 1/2 emerged  
57: Ear 3/4 emerged  
59: Ear emergence completed |
| 6     | Anthesis (flowering)  
Generally scored by noting the presence of emerged anthers (pollen sacs).  
60: Beginning of anthesis (few anthers at middle of ear)  
65: Anthesis half-way (anthers seen half-way to tip and base of ear)  
69: Anthesis complete |
| 7     | Milk development  
Score starch development in the watery kernel.  
70: Kernel water ripe (no starch)  
71: Kernel water ripe (no starch)  
72: Early milk  
73: Medium milk  
77: Late milk |
| 8     | Dough development  
Kernel no longer watery, but still soft or dough-like.  
80: Dough development  
83: Early dough  
85: Soft dough  
87: Hard dough |
| 9     | Ripening  
90: Grain hard, difficult to divide  
91: Grain hard, not dented by thumbnail  
92: Grain looseness in daytime  
93: 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 |
CHAPTER ONE

Growth and Development

Root growth

Barley has two distinctive root systems. The first roots that arise from the seed are called the primary or seminal root system. After germination, between five and seven roots grow and branch as they extend deep into the soil. The seminal roots form the deepest root system and given adequate moisture and soil of reasonable structure, will grow to about 2 metres in depth.

The second root system develops from the crown of the plant and is known as the nodal or secondary root system. The appearance of nodal roots is closely linked to tiller development and any tillers which may become detached from the main stem can grow supported by nodal roots only. The nodal roots grow horizontally for a while before growing downwards and branching. The layers of soil close to the surface are thus dominated by nodal roots.

Root growth ceases at around ear emergence and then roots start to die off. The structure of root systems varies among barleys of different origins. Types that originate from areas with a high frequency of drought tend to have a deep rooting pattern while those from higher rainfall areas have comparatively shallow root systems.

In waterlogged conditions, the nodal roots have air spaces (aerenchyma) which supply oxygen to the root system that is formed under these conditions. Under prolonged waterlogging the earlier formed roots with no aerenchyma die. Barley roots will not grow through free water or dry soil, so the concept that under dry conditions barley roots will grow down 'in search of water' is entirely wrong.

The control of flowering date in barley

Daylength sensitivity

The timing of ear emergence in barley is controlled by the plant’s response to daylength and temperature. Barley is known as a ‘long day’ species in that its development rate is fastest under long daylengths and may be inhibited under shorter days. The sensitivity to reduction in daylength varies greatly among barley varieties. When a daylength sensitive variety is exposed to short days it responds by forming more leaves in its main stem before initiating the ear. For example, Stirling barley, sown in the relatively long days of December, will flower with only six leaves on the main stem. By contrast, the same variety sown in the short days of June will form 11 or 12 leaves on its main stem before flowering. A daylength insensitive variety will form a set number of main stem leaves regardless of sowing date.

The rate of leaf appearance is controlled by temperature, therefore a warm December sowing of Stirling will not only produce fewer main stem leaves but they will appear in a shorter time per leaf. The process commonly referred to as bolting is a crop that has reached ear emergence far too quickly, usually as a result of an early sowing with relatively longer daylengths that is followed by a period of high temperatures.
A crop that has bolted will have fewer main stem leaves, so fewer opportunities to tiller, lower yield, and will be more susceptible to frost damage and stunting because of the early flowering date. To avoid bolting when trying to take advantage of early sowing opportunities, a variety must have the capacity to delay development if sowing is followed by a warm spell. This capacity to delay development is provided for by a vernalization response, or cold requirement to initiate development.

**Vernalization response**

In varieties that are vernalization responsive, the shoot apex remains in the vegetative phase, forming leaves until it has experienced a certain number of ‘cold’ hours. While vegetative, the plant generally adopts a very flat or prostrate growth habit. In a northern hemisphere winter this ensures that the plant remains beneath the snow and is protected from the extremes of cold above the snow.

Winter barley is a crop which will not flower until they have grown through the winter months. After the plant has received its required period of cold it is said to be fully vernalized and the shoot apex moves into the reproductive stage and begins to initiate the floral primordia. The number of cold hours, or vernalization response, required to reach floral initiation varies greatly among winter varieties, probably depending on the severity of the winter in the region in which the vernalization genes evolved.

**Basic vegetative period**

A third factor controls development in barley and is known as the basic vegetative period (BVP). The easiest way to explain BVP is the minimum number of main stem leaves that are formed when a plant has had its vernalization response satisfied and is grown in a long photoperiod. This minimum leaf number can vary from as few as six (e.g. Stirling sown in summer) to as many as ten (e.g. the European variety Triumph). There is a further tendency in varieties with a large minimum leaf number for the leaves to emerge at a slower rate. The BVP of a plant is the ‘foundation’ on which a development response is built. A variety with a long BVP will be relatively late maturing and this may be further accentuated by addition of genes for daylength sensitivity and vernalization.

By contrast, a variety that has a short BVP will be able to adapt to both long and short growing seasons when the short BVP is combined with the appropriate genes for daylength sensitivity and vernalization. A good example of this is the South Australian variety Skiff, which combines a short BVP with a high level of daylength sensitivity. When sown in May, Skiff slows its development in response to the short daylength, tillers profusely and can yield as high as 5 t/ha. When sown progressively later it speeds up its development until very late sowings, such as August, flower only a few days later than the early maturing Stirling.
Development in Australian varieties

Spring barleys are those that are adapted to spring sowings in the northern hemisphere and so do not carry a vernalization response. Most Australian barley varieties are true spring types, which in practical terms means that if sown earlier than their optimum sowing time they are liable to bolt.

The earliest maturing Australian varieties, such as Ketch (South Australia) and Yagan (Western Australia), have a shorter BVP and low level of daylength sensitivity. Slightly later varieties such as Stirling (WA), Clipper and Schooner (South Australia), are also short BVP but slightly more daylength sensitive. Later again is Skiff (South Australia) which has a short BVP but a high level of daylength sensitivity, and Onslow which has a longer BVP and low daylength sensitivity. The late maturing Franklin (Tasmania) has a very long BVP and mild daylength sensitivity, and is a good example of how a long BVP limits a variety's ability to adapt to a range of regions and sowing dates.

The only locally released variety that could be described as 'winter' is Ulandra (New South Wales) which has a very mild vernalization response, mild daylength sensitivity and a very long BVP. In future, winter varieties are likely to be released to growers who are attempting to sow as early as possible, especially in the higher rainfall areas where waterlogging may be a problem. A basic understanding of the factors controlling development in each variety give a reasonable guide as to the sowing dates and regions to which it will be best adapted.
2. SETTING THE POTENTIAL

Kevin Young
Esperance Agricultural Centre

"Soil is without doubt the first and most important part of the whole question. From all information obtainable and from my own practical experience, I have no hesitation in stating that the best barley is grown on light, loamy soil... Therefore the most profitable ground to grow malting barley on is land with a friable surface, as it is more easy to cultivate, and will grow a more suitable grain for malting purposes than that which is grown upon a stiff or waxy soil."

Extract from Growing barley for malting purposes - hints to our farmers by Chris Redwood, Mallister
Journal of the Department of Agriculture, Western Australia, April 1900

Barley can be successfully grown over a wide range of soil types and rotations. To obtain an economic comparison between a barley crop and alternative crops we must estimate the likely yield of barley compared with these other crops in the range of soil types and rotations that are available.

The most common decision facing the mixed cereal grower is the choice between barley and wheat. Traditionally, barley prices are lower than Australian Standard White (ASW) wheat. In the past decade the price for malting barley compared with wheat has been such that a 5 per cent higher yield of malting barley relative to wheat is needed to obtain equal financial returns (Figure 1a). For feed barley the figure is even higher, and an extra 25 per cent yield is required for returns to equal an ASW wheat crop (Figure 1b). The yield potential of a barley crop is set when the soil type is chosen and the paddock is prepared for cropping through the appropriate rotation.

Soil type and rotation

Selection of soil type and aspect along with rotation are critical to the yield and quality of a barley crop. One of the major factors influenced by soil type and rotation is nitrogen supply. The principles of nitrogen nutrition are covered in more detail in the chapter on ‘Crop nutrition’. This section discusses, in broad terms, the effect of various combinations of soil type and rotation on nitrogen supply and likely grain protein levels that will result. Any combination which leads to high grain protein in a wheat crop will likewise give a high protein barley crop (Figure 2).

![Figure 1. Yield required for equal returns from barley relative to ASW wheat: (a) malting barley. (b) feed barley](image)

![Figure 2. Relationship between grain protein of Stirling barley and Spear wheat grown on the same site](image)

Because maltsters require grain of moderate/low protein it is best to reserve high nitrogen situations for the production of high protein wheat. This will give a better return on investment in almost all years. Some of the basic principles that must be considered when choosing combinations of soil type and rotation most suited to barley production are:
• Waterlogging - barley is highly susceptible to waterlogging, therefore paddocks considered a high risk should be avoided.

• Root diseases - in the southern areas the root disease take-all is a major factor limiting yield; while wheat is very susceptible, barley has some tolerance but very high take-all situations should be avoided.

• Acidity - barley is very susceptible to soil acidity and associated aluminium toxicity. Soils with a low pH and a soil profile that becomes more acidic with depth (e.g. wodgil soils) should be avoided. Mildly acidic soils that become neutral with depth are well suited to barley production.

• Alkalinity - barley grows well on most alkaline soils with the exception of those high in boron. Many barley varieties are susceptible to boron toxicity (particularly the popular malting variety Stirling). Many wheatbelt soils have higher levels of boron at depth and become increasingly alkaline with depth, making boron more available to plants. Susceptible barley varieties have poor root growth in the high boron layer and are less able to extract water at depth than resistant varieties. Susceptibility to boron toxicity is more of a problem in drier years.

• Salinity - some of the finer textured (high clay content) soils become increasingly saline with depth; on these soils, barley has a substantial yield advantage over wheat owing to its tolerance of salinity.

Beware, however, of combining waterlogging and salinity.

• Soil texture - in general terms the most favourable situations for barley production will be on the lighter, sandy (coarse textured) soils which have a relatively low nitrogen status, and are not likely to be a high waterlogging risk.

Choice of rotation
The main factors which are affected by rotation are:

• soil nitrogen supply;
• level of root diseases carried in the soil;
• foliar diseases carried on the stubble residues.

Examples of rotations and their suitability for the production of malting barley

• Following field peas - on heavy soils, barley following peas is likely to lead to high protein levels in most years, rendering it unsuitable for malting. Feed barley can be grown in this situation but the returns are unlikely to be competitive with high protein wheat.

• Second cereal following peas - because foliar diseases are a major problem with peas, we recommend that two cereal crops are grown before returning to peas. Barley is well suited to the role of second cereal in the rotation unless soil nitrogen levels are very high.

• Following lupins - on light soils, barley following lupins is likely to yield well but the protein level may be a problem depending on soil nitrogen supply. If, on your farm, wheat following lupins generally gives protein levels of 10.5 per cent or more then it is likely that soil nitrogen will be too high for malting barley. Likewise, wheat protein levels of 10.5 per cent or less indicate that malting barley can be safely grown in most years.

• Second cereal following lupins - because foliar diseases can be a problem with lupins in the northern part of the State we recommend that two cereal crops are grown before returning to lupins. The low incidence of take-all in the north makes barley well suited to the role of the second cereal in the rotation. In the south, where take-all levels will be high following the wheat crop, barley yield is likely to be restricted to around 2 t/ha when grown as the second cereal.

• Following canola (or linseed) - with the advantage of low root disease incidence and reduced soil nitrogen supply after oilseeds, this is the ideal situation for the production of plump malting barley that is not too high in protein.

• Following oats - this rotation is again well suited to the production of malting barley as take-all will be reduced and soil nitrogen level lowered. Remember that oats are quite tolerant of waterlogging whereas barley is very
susceptible, so be careful not to choose a high risk waterlogging paddock on which oats happened to have yielded well.

- **Following pasture (north)** - in northern areas, the suitability of barley as a crop after pasture will depend on the soil nitrogen status and soil type. After a good medic stand on heavy soils it is likely that soil nitrogen would be too high and wheat would be a much more profitable alternative. On lighter soils with a weaker clover base, barley would be a better proposition.

- **Following pasture (south)** - once again the combination of heavy soils and medic pasture should be better used for wheat production. On the lighter soils, with a strong clover base that has been chemically manipulated to remove grasses early in the growing season, wheat may be the most profitable alternative. Complete removal of grasses is rare and does not completely eliminate take-all. There are many situations where take-all has been reduced enough to enable barley, with its tolerance of low levels of the disease, to yield significantly more than wheat. Very grassy pastures that will be carrying an extremely high take-all burden should be avoided.

**WATERLOGGING**

**Robert Belford**

South Perth

Barley is very susceptible to waterlogging and, as a general principle, barley should not be sown in paddocks that waterlog regularly. There are, however, substantial areas of the medium/high rainfall zone which are waterlogged only occasionally. On these areas, high yielding barley crops can be grown provided that waterlogging does not persist for more than a few weeks. Management of such soil types can help to reduce the impact of waterlogging in the years in which it occurs. The following section discusses waterlogging in detail, and ways of minimising its impact.

Waterlogging occurs when rainfall exceeds the drainage capacity of the site, the internal drainage rate of the soil, and the water storage capacity of the soil profile. Soil types most likely to waterlog are either duplex soils (which have a shallow sandy topsoil of low water holding capacity overlying a clayey subsoil with very low permeability); or fine textured clayey soils which have a low infiltration capacity. Duplex soils occur widely in the cropping areas of Western Australia (Figure 3).

The occurrence of waterlogging, and its effect on barley production depend on site and soil properties, and the amount and timing of rainfall. Crop losses due to waterlogging vary widely from year to year; however, a recent analysis for the Shires of Brookton, Pingelly, Narrogin and Wagin in a year of average rainfall suggested $23 million was lost in crop production from waterlogging. Over the State, the potential loss of crops and pastures in a wet year is enormous.
Effects of waterlogging on the soil environment

Between 10 and 60 per cent of the volume of well drained soils is gas space. Oxygen (essential for roots of crop and pasture plants, and some micro-organisms) and carbon dioxide (produced by these organisms) can move freely in and out of the profile.

However, when a soil is waterlogged, most of this gas space is filled with water. Gases move about 10,000 times more slowly through water than air, so once the oxygen in the soil profile has been used, oxygen cannot enter the profile quickly enough to satisfy plant requirements.

Carbon dioxide and other gases cannot escape quickly, and build up in waterlogged soils (Figure 4). The rate at which oxygen disappears from the soil depends on soil temperature, and also on the amount of organic matter in roots and micro-organisms, which creates the demand for oxygen. Once oxygen levels in soil start to fall, a series of chemical changes takes place; of these, the loss of nitrogen by the reduction of nitrate to nitrogen and nitrous oxide gases (denitrification) is the most serious.

For crops in Western Australia, the most important changes in soil which affect plant growth are the decline in oxygen, the increase in carbon dioxide and ethylene, the loss of nitrate, and the changed solubilities of iron and manganese (which give waterlogged profiles their characteristic mottled appearance).

Effect of waterlogging on growth

When oxygen is depleted from soil, roots are unable to produce the energy required for normal metabolism; hence root growth slows, and root tips (which have the greatest need for energy) may die. Slow root growth means low rates of uptake of nutrients (some of which are less available anyway - e.g. nitrate), and more limited exploration of the soil profile by roots. This in turn leads to slower shoot development and growth. Leaves of waterlogged cereals...
often have lower concentrations of nitrogen, phosphorus and potassium than leaves of plants in well drained soils. During waterlogging, plants translocate nitrogen from the older leaves to maintain growth of the younger leaves. This gives rise to the characteristic chlorosis (yellowing) of older leaves.

Restricted root growth throughout the soil profile early in the season can limit the uptake of water later in the season, leading to poor grain fill and possibly lower grain yield. The effects of waterlogging on plant processes are summarised in Table 2.

![Early seven crops (on right) show less waterlogging damage](image1)

![Dark green patches are small plots with high nitrogen applications](image2)

Table 2. General effects of waterlogging on growth of cereal crops

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>EFFECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germination and emergence</td>
<td>Can be seriously reduced</td>
</tr>
<tr>
<td>Root growth</td>
<td>Slowed, roots may die, limited exploration of soil profile; root systems have some capacity to compensate for waterlogging damage by producing new roots with better internal structure for gas movement (aerenchyma)</td>
</tr>
<tr>
<td>Nutrient uptake</td>
<td>Reduced for most nutrients (including nitrogen, phosphorus and potassium); can be increased for sodium, iron and manganese</td>
</tr>
<tr>
<td>Shoot growth and development</td>
<td>Development is delayed, growth is slowed; yellowing (chlorosis) of older leaves and tillers</td>
</tr>
<tr>
<td>Tillering, and number of ears</td>
<td>Start of tillering delayed, tillering inhibited (may be compensatory tillering after waterlogging in barley); number of ears usually depressed</td>
</tr>
<tr>
<td>Stem growth</td>
<td>Waterlogging restricts growth of stems and shortens plant height</td>
</tr>
<tr>
<td>Grain number per ear</td>
<td>Likely to be reduced if waterlogged during early stem elongation</td>
</tr>
<tr>
<td>Grain size (weight)</td>
<td>Reduced if poor root growth delays development and restricts water uptake</td>
</tr>
<tr>
<td>Grain protein</td>
<td>Likely to decrease after waterlogging early in season (low N uptake); but may be increased if waterlogged late in season (reduced grain size)</td>
</tr>
</tbody>
</table>
Effect of waterlogging on grain yield

Barley has a lower tolerance of waterlogging than oats or wheat when waterlogged under both saline and non-saline conditions. Actual yield losses after waterlogging depend on the severity of waterlogging (a combination of the height of the water-table relative to the soil surface, and the duration of the waterlogging), and the timing of waterlogging in relation to the stage of crop development.

Timing of waterlogging in relation to yield loss

All crops appear least tolerant of waterlogging between germination and emergence, when growth of the seedling is severely reduced because insufficient oxygen diffuses through water films surrounding the seed. Research conducted in the United Kingdom showed that 10 days of waterlogging before emergence can kill all plants; waterlogging for four and six days can reduce barley plant populations by 50 per cent and 80 per cent respectively compared with the number established in well drained conditions (Figure 5). However, the barley plants increased tillering to offset some of these plant losses, such that yield reductions were only 20 per cent and 50 per cent respectively of those in well drained soil.

The most sensitive stage of growth for the barley crop after emergence is difficult to define from field observations as it is rarely possible to define the particular waterlogging event that contributes to poor plant growth. Experiments in pots to define critical growth stages can be misleading as conditions are usually not the same as those experienced by field crops; nevertheless, such experiments suggest that waterlogging when the crop is growing rapidly during stem elongation can have serious effects on yield (Table 3).

Yield losses in the field

Field experiments usually show variable effects on yield because the severity and timing of waterlogging varies widely from paddock to paddock and year to year. The presence of excess water does not always mean that oxygen has been lost from the soil profile; wet conditions when temperatures are low (and

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Table 3. Effects of 10 days waterlogging at different growth stages on yield of barley (pot experiments; Stepniewski and Labuda, 1989)

<table>
<thead>
<tr>
<th>Stage of growth when waterlogged</th>
<th>% yield reduction relative to well drained plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st leaf</td>
<td>0</td>
</tr>
<tr>
<td>3rd leaf</td>
<td>22</td>
</tr>
<tr>
<td>1st node</td>
<td>48</td>
</tr>
<tr>
<td>3rd node</td>
<td>53</td>
</tr>
<tr>
<td>Heading - beginning</td>
<td>42</td>
</tr>
<tr>
<td>Heading - end</td>
<td>0</td>
</tr>
<tr>
<td>Milk ripe grain</td>
<td>0</td>
</tr>
</tbody>
</table>
therefore oxygen demand by the plants is low, and growth is slow) often have little effect on crop performance. Yield reductions after waterlogging range thus from 0 to 100 per cent, the latter usually associated with crop losses after pre-emergence waterlogging. Typically, however, barley yields are depressed by 20 to 25 per cent after waterlogging in winter.

Field experiments carried out on a duplex soil in the Narrogin area confirm that there is a good relationship between the severity of waterlogging (expressed as the mean height of the perched water-table) and grain yield (Figure 6). In this case, grain yields appear to reach a maximum when there is at least 50 centimetres of well drained soil; however, yields were reduced by around 30 per cent when the average water-table height was about 20 centimetres below the soil surface. Figure 6 also indicates that complete waterlogging of the profile during the season would have led to no grain production at all.

Surveys around Narrogin have shown strong positive correlations between grain yield (usually wheat) and rainfall in April and May, probably because of good pre-planting moisture storage but little waterlogging; but strong negative correlations between yield and rainfall in June and August when high rainfall is linked to lower yields. High rainfall in June implies waterlogging of young plants, whereas waterlogging in August is likely to coincide with higher soil temperatures when crops are starting to grow rapidly and have a high demand for oxygen and nutrients. Yields were reduced least when crops were waterlogged in July (low temperatures, slow growth).

**Effects of waterlogging on grain quality**

Little work has been done to define the consequences of waterlogging on grain quality for specific end-uses such as malting. Interference with nitrogen uptake following waterlogging in winter could be expected to lower grain protein levels; however, limited water uptake later in the season could raise protein content.

Nothing is known of the effects of waterlogging on protein quality, or on other aspects of quality which are important to the malting process.

**Waterlogging and salinity**

Plants survive and grow in mildly saline soils by excluding salts (particularly sodium) from their tissues, but the roots need energy to do this. In waterlogged saline soils, with low oxygen concentrations, plants have insufficient energy to exclude the sodium which therefore builds up to toxic levels in the shoots. This leads to a decrease in growth, leaf death and progressive shoot death.

The interaction between waterlogging and salinity is such that wheat that grows satisfactorily in mildly saline soil (200 milliSiemens per metre) is killed when the same soil is waterlogged. Barley has greater tolerance than other cereals to high levels of sodium in tissues in non-waterlogged soils, but suffers from insufficient energy to exclude sodium in waterlogged soils.
Strategies to minimise yield losses after waterlogging

Selection of varieties

There are many research reports of barley varieties which differ in their sensitivity to waterlogging, but there is little specific information on the varieties commonly grown in Western Australia. Franklin has been observed to be particularly susceptible to the combination of waterlogging and take-all. Field experience in Western Australia suggests Onslow is more tolerant of waterlogged conditions than other barleys.

Agronomic options

There are several agronomic options to reduce damage by waterlogging. These include:

- Plant early and use long season varieties so that crops are established before waterlogging is likely to occur, but flower at the optimum time to maintain yield and quality.

- Ensure that adequate nitrogen is available to the crop before and after waterlogging. Research shows that crops supplied with adequate nitrate can often grow away from the effects of waterlogging, and make better use of applied fertiliser.

- Minimise competition for oxygen by other plants, by ensuring that paddocks susceptible to waterlogging are free of grass and broad-leaved weeds before cropping.

- Take-all is more prevalent under waterlogged conditions than in well drained paddocks. The risks of take-all infection can be reduced by eliminating grasses from paddocks before cropping.

Site modifications

This usually implies drainage work to minimise the chances of severe waterlogging on the site. Drainage options are discussed more fully elsewhere. Whilst drainage is often seen as a drastic option, returns from investment in drainage on suitable sites are usually large. Returns from cereal crop production are improved and made more consistent from year to year, and the options for cropping and land use can improve markedly. Land initially suitable only for pasture and occasional cereal crops can be put into crop rotations which include higher value crops.

Further reading


Other Farmnotes in relation to drainage and soil management:

Farmnote No. 70/89 Reverse-bank seepage interceptor drains (Agdex 572).

Farmnote No. 71/89 Surveying and construction of reverse-bank seepage interceptor drains (Agdex 572).

Farmnote No. 120/84 Spoon and W drains (Agdex 572).

Farmnote No. 46/92 Cropping duplex soils (Agdex 100/511)

Farmnote No. 32/85 Gypsum improves soil stability (Agdex 514)

Farmnote No. 57/90 Identifying gypsum responsive soils (Agdex 514)
3. CHOICE OF VARIETY AND SOWING DATE

Kevin Young

Esperance Agricultural Centre

"I am a great believer in early sowing, and all authorities on barley growing strongly advocate it. I suppose many farmers will not agree with me on this point. However, I will try by logical facts to prove this assertion right. Early grown barley has a great advantage over late, as it is rooted and stooled before spring. So that as soon as winter is over it is off, and gets well developed before the hot sun has time or power to force it to ripen before intended by Nature, and so will grow to perfection and produce that quality which is essential for good malting barley - namely starch - and when it is malted constitutes the diastase or saccharine matter necessary to make beer. Now in late sown barley the whole process is hurried, and before it has time to come to maturity, the hot rays of the sun are forcing it too rapidly; and in consequence your barley instead of developing starch which is essential for mellow grain, it has acquired, by being forced, too much gluten. Using a malting phrase it becomes steely, glossy, or flinty, and comparatively useless to the maltster."

Extract from Growing barley for malting purposes - hints to our farmers by Chas. Redwood, Maltster
Journal of the Department of Agriculture, Western Australia, April 1900

Stirling
Sown: May 23
Z57: Sept. 10

Stirling
Sown: July 20
Z57: Oct. 5

Stirling barley showing increased weather staining of grain with early sowing

Barley is grown in many different farming systems: by farmers cropping large areas in the low rainfall wheatbelt through to predominantly woolgrowers sowing a small area of crop in the high rainfall areas.

The choice of variety and sowing date depends on barley's place in the cropping system as much as the rainfall and growing season available to it. For example, the large wheatbelt cropping enterprise may sow lupins first, followed by wheat and peas, with barley being used as a rapid maturing, drought tolerant crop sown last in the program. By contrast the high rainfall woolgrower can generally have barley sown by mid-May with good planning and an average break to the season.
Ulandra
Sown: May 23
Z57: Oct. 8

Ulandra
Sown: July 20
Z57: Nov. 5

In choosing a variety, the first consideration is therefore to select one with the appropriate maturity, given the likely sowing date and region. A barley variety of the right maturity basically means that it reaches ear emergence at the optimum time - often called the flowering window. If a crop flowers too early, then it will not have maximised growth before flowering and yield will be lower than it should have been. This is the case for crops that are said to have bolted. Flowering too early exposes the crop to an increased risk of frost and a greater chance of discolouration of grain as a result of weather staining.

By contrast, crops that flower too late risk running out of soil moisture and filling grain under higher than optimum temperatures. This also leads to lower grain yield and smaller grains that are high in protein and low in malting quality.

The control of development in barley is based on the variety's response to daylength and temperature. Varieties fall into two broad groups known as spring and winter types.

Winter barleys are more commonly grown in the northern hemisphere where they are sown in autumn and develop slowly during the winter months in which they may be required to survive for a period under snow. Their early development is controlled by a vernalization response, which basically means that the growing point produces leaves until a certain number of 'cold hours' have been accumulated.

Spring barleys in the northern hemisphere are sown after the snow thaws and mature rapidly as they have no vernalisation response. The traditional Australian varieties are spring types. Within these two groups the varieties are then categorised as either early, medium or late maturing.

The maturity groups of some commonly grown Australian barley varieties are listed in Table 4.

<table>
<thead>
<tr>
<th>Maturity Groups</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very early spring</td>
<td>VE Yagan, Ketch</td>
</tr>
<tr>
<td>Early spring</td>
<td>E Stirling, Windich, O'Connor, Schooner, Clipper</td>
</tr>
<tr>
<td>Medium spring</td>
<td>M Onslow, Skiff, Morrell, Moondyne</td>
</tr>
<tr>
<td>Late spring</td>
<td>L Franklin</td>
</tr>
<tr>
<td>Winter</td>
<td>W Ulandra</td>
</tr>
</tbody>
</table>
After choosing the sowing date that best suits your cropping system the next step is to choose the most appropriate maturity group for your area. The Western Australian Department of Agriculture publishes the Crop variety sowing guide for Western Australia annually. This divides the Western Australian cereal growing areas into five zones, and within each zone, three to four rainfall regions.

Recommended varieties will change from year to year, but the maturity group that is the most appropriate for your zone and sowing date will be relatively stable. Table 5 lists the most appropriate maturity group for your zone and a range of sowing dates. Refer to the most recent version of the Crop variety sowing guide for Western Australia for up-to-date information on malting and feed varieties that are available, along with information on the maturity group that they represent.

### Choice of sowing date

When deciding whether to sow barley early or late in the cropping program, a number of factors must be taken into account. First, what are the advantages and disadvantages of early sowing? By sowing as early as possible with a later maturing variety:

- the crop will have the opportunity to give the highest possible yield;
- the grain protein content will be lower (one month delay in sowing date can increase protein by about 1 per cent);

- foliar diseases will be more severe;
- in good growing conditions the crop will be taller and may lodge.

A variety that is well adapted to early sowing will therefore have a high level of foliar disease resistance, and preferably be a dwarf variety so that lodging and associated yield loss do not occur.

The foliar diseases that are most prevalent vary greatly from the north to south of the cereal growing areas and are covered in detail in the Chapter 8, 'Leaf diseases of barley'. The Crop variety sowing guide for Western Australia gives details on disease resistance, height and straw strength for each variety.
The only reasonable measures that can be taken to ensure that frost risk is minimised are to delay sowing and avoid high risk areas of paddocks. Aspect in the landscape is important in relation to frost risk. Valley floors are the most susceptible areas and hill tops have the lowest risk of frost. In Table 5, a range of optimum sowing dates is given for barley varieties in each maturity group. By sowing as late as possible in that range, the crop will still flower in the optimum window, but it will be as late as possible to minimise frost risk. Because frosts are far less frequent than the dry spell that occurs after the optimum flowering time, in the long run it does not pay to delay flowering any later.

By sowing late in the program with an early maturing variety:

- the crop will be lower yielding with high grain protein;
- foliar diseases and lodging will be much less severe.

**Frost risk**

Barley is very similar to wheat in its susceptibility to frost. The most damaging stage for frost is after ear emergence. This damage may take the form of sterility if anthers are damaged early during ear emergence or shrivelling of grain if the frost event occurs during the milky ripe stage. Spring frosts occur irregularly in Western Australia and susceptibility varies with region (Figure 7).
4. CROP ESTABLISHMENT

"A great many theories exist regarding the proper amount of seed to be sown to the acre: but from my knowledge of the soil of this colony I would strongly advise the following quantities. If drilled, 40 lbs to the acre; and if sown broadcast, one bushel, but of course no set rule can be put down for this as the quality largely depends on the richness of the soil. The seed used should be the best procurable, not over twelve months old, and the farmer should change his seed every second season. It is advisable to select seed grown in your own country if possible. But still there is no fear about its growing capacity if grown in the colonies.

A common fallacy exists that inferior seed will show as good results as that grown from prime seed... If you sow a good bold grain it throws off stronger roots, and the stalk is better able to feed its head, or ear. There is also another great point to be considered in having the best seed, and that is that should there be a bad year the seed that throws off the powerful roots is able to stand more privations than that with weak ones."

Extract from Growing barley for malting purposes - hints to our farmers by Chas. Redwood, Maltster Journal of the Department of Agriculture, Western Australia, April 1900

SOWING RATE AND DEPTH

Kevin Young
Esperance Agricultural Centre

Successful crop establishment involves the germination and emergence of the optimum number of plants which grow and develop with strong seedling vigour. With seedling vigour, the young plants are better able to tolerate pathogens and insects. Healthy seedlings are also better able to compete for space and nutrients with emerging weeds, and will be more tolerant of applied herbicides.

Plant population and seeding rate

Extensive research in all cereal growing regions has shown that there was very little effect of variety, sowing date or location on the optimum plant number. Yield increases up to about 100 plants per square metre and levels off thereafter (Figure 8).

Plant populations in excess of 100 plants per square metre have the effect of marginally reducing seed weight (Figure 9).

For varieties such as Franklin, which have long narrow grains, it is important to aim for the highest possible grain weight so as to avoid being downgraded because of a high level of screenings. Therefore with Franklin and similar varieties it pays to keep as close as possible to 100 plants per square metre, while plump grained varieties like Stirling can be sown safely at higher plant populations. Figure 10 shows that Stirling is plumper for the same grain weight and less likely to give higher screenings at higher plant populations.
Barley differs from wheat in that as wheat yield increases with higher rainfall, the optimum plant population increases, so that for wheat yields of 4 t/ha or more the target population is around 200 plants per square metre. By contrast, barley tillers profusely and can easily exceed 4 t/ha with only 100 plants per square metre.

### Calculating a seeding rate

The rate of seed in kilograms per hectare that will be required to achieve 100 plants per square metre will depend on seed size, and on the number of seeds that are likely to establish successfully. After grading the average seed weight could vary from 35 to 45 mg depending on variety and how well the grain filled in the previous spring.

To determine the seed weight, count and weigh 1000 seeds of the graded sample. If you do not have the facility to weigh a sample then Table 6 can be used as a guideline. Establishment can vary from as low as 55 per cent with early May sowings on water repellent sands through to as much as 85 per cent with later sowings when the soil has wetted up fully. Establishment of 80 per cent of seeds sown is considered good.

Table 6 shows that Franklin barley, grown from a seed sample with an average seed weight of 40 mg, and assuming a good establishment of 80 per cent, would require a seeding rate of 50 kg per hectare.

<table>
<thead>
<tr>
<th>Percentage establishment</th>
<th>Seed weight 35 mg</th>
<th>40 mg 'Plump'</th>
<th>45 mg 'Plump Stirling'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assume target is 100 plants per square metre</td>
<td>'Light'</td>
<td>'Plump'</td>
<td>'Plump Stirling'</td>
</tr>
<tr>
<td>55</td>
<td>64</td>
<td>73</td>
<td>82</td>
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<tr>
<td>85</td>
<td>41</td>
<td>47</td>
<td>53</td>
</tr>
</tbody>
</table>

### When are more than 100 plants per square metre an advantage?

Situations in which the optimum plant population is likely to exceed 100 plants per square metre are generally those where the crop is stressed and tiller numbers reduced, for example:

- mid-season waterlogging which is severe enough to reduce tiller number;
- high weed infestations which compete for space and nutrients;
- heavy insect attack which causes seedling mortality.

### Seeding depth

The optimum depth of sowing for barley is no more than 3 cm. When barley is sown too deep, yellow horizontal stripes appear across the first leaves.

The consequences of deep sowing can include:

- long and limp seedling leaves that are easily damaged by wind and insects;

In higher yielding crops in the high rainfall areas there is evidence that the ability of the crop to intercept light is more of a limitation to yield than water. For this reason it is better in these areas to cover the soil as early as possible to maximise light intercepted by the crop canopy and convert it to extra yield. While more work is required on this factor in our higher rainfall areas, evidence from overseas suggests that for crops that are expected to yield in excess of 4 t/ha, rows should be no further apart than 25 cm and preferably less than 20 cm.

### Row spacing

The optimum row spacing for barley varies according to the yield expectation. In general the standard combine setting of 18 cm is adequate for even the highest yielding crops. Trials conducted in the lower rainfall areas have indicated that rows can be widened to 27 cm or even 36 cm without yield loss. In these situations crop yields are typically in the order of 2 to 3 t/ha and water is the major limitation to yield.
• reduced root development, making plants more susceptible to damage by root diseases such as take-all and rhizoctonia patch;

• delayed plant development and reduced tillering (Figure 11);

• delayed emergence and poor seedling vigour that can reduce competitiveness with emerging weeds;

• having to delay weed spraying in order to enable the barley plants to reach the safe development stage.

After germination the coleoptile pushes to the soil surface providing protection for the first emerging leaf and ceases growth as soon as it is exposed to light at the soil surface. The coleoptile has a maximum length to which it can grow and this length is related to the height that varieties reach at flowering.

For any variety the coleoptile length is also controlled by temperature, with the optimum length reached at around 15°C. In tall barley varieties, such as the old malting barley Prior, the coleoptile can reach 100 mm, compared with Clipper at 87 mm, while the dwarf varieties may reach 70 mm or less. If the temperature drops to 5°C, the coleoptile length is reduced to about two-thirds of its maximum. Seed dressings such as Baytan® and Armour® also reduce coleoptile length.

![Image of Skiff barley 6 weeks after sowing at two depths showing difference in development]

![Image of Yellow striping caused by deep sowing (plant on right)]

**Figure 11. Effect of sowing depth on development of Skiff barley six weeks after sowing**
Deep sowing can be avoided by the use of press-wheels which compress the soil directly above the seed. Using a standard tined combine without press-wheels, the seed is often spread through a depth of 2 to 3 cm. To avoid sowing too deep there must be the occasional seed left on the soil surface. This is far better than having all seed covered and most of the crop sown too deep. Sowing into water repellent sands early in the season, where the wet soil may be at 5 cm or more, necessitates the use of press-wheels and possibly wetting agents sprayed into the furrows to ensure even establishment. Early sowing has the advantage, that with the warmer soil temperatures, coleoptile lengths will be greater than for later sowings in winter.

Sowing plump seed at the right depth is an important first step towards achieving vigorous, healthy seedlings. The second major factor is to use the appropriate level of soil disturbance to create the environment for rapid growth and development.

### TILLAGE

**Ron Jarvis**

South Perth

**A brief history**

Until the 1970s Western Australian farmers did not question the need for cultivation as a necessary part of cereal growing. Cultivation was considered essential to:

- kill weeds;
- prepare a seedbed;
- aerate and loosen the soil for better root growth;
- mineralise soil nitrogen and other nutrients to a plant-available form;
- control root diseases.

Nevertheless, most Western Australian farmers still cultivated less than Australian and world standards.

The non-selective, non-residual, desiccant herbicides, paraquat and diquat discovered in the 1950s and first sold commercially as Spray.Seed® in Western Australia in 1972, were catalysts for the minimum tillage revolution.

The rapid rise in acceptance of crop establishment via minimum tillage, with its dependence on a knock-down herbicide, was promoted by the introduction of Hoeggrass® in 1978, for post-emergence ryegrass control, and the use of cheap and effective in-crop, broad-leaved weed control by mixing diuron with MCPA and 2,4-D. Direct-drilling was the term coined for the system which relied on these herbicides to control all weeds and used only the cultivation while sowing the crop. By 1983, direct drilling was being used on about one million hectares.

The ideal tillage strategy is one that controls weeds, maintains soil structure, will not cause erosion, controls root disease, allows early sowing, establishes good plant density with early vigorous growth, gives the greatest yield and quality and costs the least.

No single system is likely to be ideal for all soils and situations, but the following sections will help producers develop conservation-conscious tillage systems that will maximise yield and net returns for their particular farms.

### Summary of tillage strategies

**Fine-textured soils**

The fine-textured soils include the salmon gum-gimlet soils of the eastern wheatbelt and the widespread ‘grey clay’ and moort soils.

**Characteristics** -

Surface structure degrades rapidly under cultivation, leading to slaking and crusting.
Tillage strategy -
Direct-drill. Reduce cultivation to a single working and use gypsum if necessary to establish a direct-drilling system. Provided a machine can penetrate to establish the crop, direct-drill with no-till is an excellent alternative on these soils.

Loams and gravelly loams
Characteristics -
Not responsive to cultivation.

Tillage strategy -
Can be successfully direct-drilled with or without soil disturbance during the seeding operation. At the sandier end of the range of these soils, some disturbance below the seed is desirable.

Yellow earths and earthy sands
The extensive deep yellow sands found throughout the central, eastern and northern wheatbelt.

Characteristics -
Can form hard-setting surface crusts or those soils with a lower clay content can be loose when dry. These soils compact under the influence of rainfall and traffic and are highly responsive to cultivation.

Tillage strategy -
Deeper cultivation (when the soil is moist) before, during or after seeding (deep ripping) will give large yield increases. Direct drilling with little disturbance will be uneconomic.

Yellow earths with acid subsoils
Soil acidity in the yellow earths is a particular problem throughout the eastern and north-eastern wheatbelt.

Characteristics -
Hard-setting surfaces and highly acidic subsoils. Exhibits compaction pans.

Tillage strategy -
Direct-drilling can be used as subsoil acidity usually negates any advantages obtained from cultivation. Responses to tillage and deep ripping occur but only when adequate soil moisture is available for the maturing crop.

White sands
Characteristics -
Coarse-textured grey and white sands. These do not form surface crusts and are susceptible to wind erosion. Rhizoctonia patch may be a problem.

Tillage strategy -
Reduced cultivation and protective surface cover are essential to reduce the risks of wind erosion. Cultivation below the seeding depth reduces rhizoctonia patch. Cultivation and deep ripping increase crop production on the deeper sands over clay. Shallow duplex soils do not respond to these workings but cultivation below the seed is often required for rhizoctonia control.

Sandy-surfaced soils
Sandy-surfaced soils cover most of the wheatbelt of Western Australia. They range from coarse textured, deep white sands to the yellow earths and yellow earthy sands found in the northern and central wheatbelt.

Research, as well as farmer experience, has found that crops direct-drilled on sandplain soils grow more slowly than crops sown after cultivation and are usually lower yielding.

The effects of cultivation
Cultivation of a sandy-surfaced soil:
• improves soil structure;
• increases available nitrogen;
• increases yield; and
• decreases some diseases.
Sandy soils have a ‘massive’ structure and do not form stable aggregates such as are found on well-structured heavy soils. Under the impact of rainfall and traffic each season, the sand grains in the surface soil pack together forming surface layers with high soil strength. Without cultivation, root growth is impeded in the surface, reducing early plant vigour and lowering grain yield.

Cultivation of the sand surfaces increases porosity - ‘opens’ the soil - and allows greater mineralisation of nitrogen. Roots grow more vigorously in the porous surface soil and extend deeper and faster. Nitrogen and soil water are used more efficiently.

Rhizoctonia patch is reduced by cultivation. The disease is found throughout the wheatbelt, but is a particular problem on southern sandplain soils.

The case for reduced tillage

While cultivation has increased grain yields on sandy-surfaced soils, there are important reasons why cultivation is not desirable. Some of these are:

- increased risk of wind erosion;
- delayed time of seeding;
- reduced organic matter;
- increased weed germination as weed seeds are brought to the surface with cultivation; and
- poorer pasture re-generation after a crop.

Tillage strategies for sandy soils

Development of the cultivation-depth-modified (CDM) combine provides an alternative to conventional tillage systems for sandy soils. Cultivation is included in the direct drilling operation and can be across the full width of the machine or have only partial surface soil disturbance.

Cultivating deep but only in narrow furrows below the seed gives a less intensive surface disturbance, but appears to loosen the soil sufficiently to overcome the detrimental effects of direct-drilling. This reduced disturbance makes the surface less prone to wind erosion, however, sometimes at a cost of more herbicides, because of the lack of ‘second knock’ effect of wide points.

The experimental CDM combine has the front cultivation tines in line with the rear seeding tines, with variable depth possible relative to each other. Thus the front tines (fitted with 5 cm wide points) could cultivate level with the seeding tines, or cultivate 2, 4, 6, 8 or 10 cm below where the seed and fertiliser would be drilled in the same pass. The CDM combine has shown advantages over scarifying in years with a wet start when nitrogen, made available following scarifying, is leached. It has outyielded ‘standard’ direct drilling on these soils in most years. The narrow slot machine appears to provide an each-way bet: it increases available nitrogen in the slot caused by tillage but leaves the between-slot area for slow release nitrogen.

Loams and gravelly loams

Unlike sandy soils, red loamy soils (such as the Avon Valley) do not respond to cultivation. Even the zero-disturbance triple disc drill has produced yields equal to or better than cultivation in a continuous cropping when adequate nitrogen is applied.
With no benefit evident from cultivation of these soils, the system of lowest cost and best erosion prevention can be employed. At the lighter end of the soil texture scale on these soils, some conservational tillage could be desirable, especially following pasture.

**Fine textured soils**

One of the limitations to crop production is often the poor structure of fine textured soils.

Many years of fallowing and cultivation and sheep traffic have caused the loss of soil organic matter and breakdown of the soil aggregates which are essential to maintaining a stable soil structure. This deterioration has been shown to decrease yield by more than 50 per cent. Inappropriate tillage regimes are the primary cause of the structural breakdown.

About 3.5 million hectares of the State's agricultural soils are susceptible to this form of soil degradation. These include the red-brown earths and red duplex soils (salmon gum and gilmet soils) common in the eastern and central wheatbelt, and the grey or moort clays of the south-western wheatbelt.

**The signs of degraded soil structure**

There is a rapid decline in the physical condition of fine textured soils after they have been cleared and cropped with cultivation for several years.

- The soil's surface sets hard when dry.
- Infiltration of rainfall is slow and water ponds on the surface during rain. Ponded water becomes cloudy from dispersed clay particles and remains on the surface for days or weeks after rain.
- Tillage is difficult. This soil is too hard when dry, but becomes slippery after only a few millimetres of rain.
- Cultivation is only possible for a few days before the soil again becomes too hard to work. (They become 'Sunday soils', too wet on Saturday and too dry and hard on Monday).
- Crop emergence is patchy because the tilled soil slakes and seals after rain, drying to a hard crust which is difficult for seedlings to penetrate.

**The importance of soil structure**

The collection of soil particles into larger units or aggregates, gives the soil its structure. The formation of these units produces pores both within and between the aggregates allowing infiltration of water and air into the soil which is vital for good plant growth. It is important that these aggregates remain stable to maintain the pores.

**How is the structure made unstable?**

The structure of the soil is broken down when the amount of the strength of the binding agents is reduced by disruptive forces breaking the aggregates into their constituent parts. These disruptive agents are the mechanical action of cultivation and traffic, the impact of raindrops on the surface and trampling by animals. Of these, cultivation is the most important cause of declining soil structure.

The result of cultivation is therefore less organic matter forming fewer bonds and those which are formed are less able to maintain a stable structure. The soil then becomes much more susceptible to disruptive force - such as raindrops - which will break down aggregates and cause the soil to slake.

**Management of fine textured soils**

**Tillage**

Minimising tillage, consistent with good crop establishment, is the key to the management of fine textured soils for crop production. Reduced tillage slows the destruction of organic matter and reduces the disruption of the binding materials which maintain a stable soil structure.

The impact of cultivation on the structural breakdown of the soil will depend on the soil type, soil moisture during cultivation, and the environment (through effects on plant growth). Tillage regimes should therefore be tailored to specific situations. Experience has shown that even where yields are not affected in the short term, excessive cultivation of fine textured soils will degrade the soil.
Pasture

There are other practices which promote a stable soil structure. Pasture increases the return of organic matter to the soil and promotes the proliferation of soil animals and fungal activity. A pasture phase provides a spell from cultivation and aggregation increases plant growth and soil organic matter. However, trampling by animals when the soil is moist and has little pasture cover can reduce soil structure.

The role of gypsum

Although reducing cultivation can delay or reverse soil structural decline and increase grain yields, the return to productivity can sometimes be slow. On some soils, application of gypsum (calcium sulphate) can hasten the rate of improvement when used with reduced tillage.

The dispersed clay particles may clog pores which will impede infiltration of water. Also, when the soil dries, the clay particles act to cement the soil constituents together forming a characteristic surface crust. Gypsum improves soil structure by reversing the dispersion of the clay particles, making the soil aggregates more stable when wet and the soil surface more friable when dry.

Unfortunately not all dispersive clays respond to gypsum because other factors, such as the concentration of the soil solution, also control the response. Some laboratory tests give a reasonable guide for predicting the response of a soil to gypsum.

It is important to first determine if a soil will respond to gypsum. If it will, the gypsum application must be supported by minimum or zero tillage and other practices which will promote organic matter build-up and aggregate binding necessary to achieve a stable soil.

Deep ripping

Deep ripping involves disturbing the soil below the normal cultivation layer, often to 40 cm, without inverting the soil. It breaks up traffic-induced, or naturally occurring compacted layers.

In the early 1980s, experiments with deep ripping in Western Australia demonstrated spectacular improvements in cereal yields.

Coarse-textured sandy soils generally have a variety of particle sizes which, when moist, are compacted by machinery travelling over the surface. Traffic pans restrict root growth, reducing plant uptake of water and leachable nutrients such as nitrogen.

Barley roots will eventually penetrate an unripped pan, but do not go as deep as where there is no hardpan, resulting in less plant dry matter production and grain yield.

The depth of the compacted layer depends on soil type. The lower the clay content of the soil, the deeper the hard layer.
Factors affecting the response to deep ripping

Deep ripping has proved extremely beneficial only on sandy soils with reasonable depth. Even on these soils in the medium rainfall area, yield responses to ripping have been variable. If pans are present, vegetative responses to ripping will almost always be obtained, but if finishing rains or soil moisture is limiting, yield responses may be not be obtained.

Medium textured soils such as the Avon Valley loams and heavier soils (salmon gum-gimlet) have not shown compaction pans, although soil strength may increase with depth. There has generally been no response to ripping, although the cultivation caused by the ripping operation sometimes has a falling effect as it kills the pasture. This is not a ripping response as it is also obtained (at a fraction of the cost) with a shallow cultivation or a herbicide spray.

Duplex soils of sand over clay and sand over gravel may develop traffic pans if the sand is deep enough. Generally sand over clay soils will not respond to ripping unless the clay is deeper than 30 cm. Sand over gravel soils have responded to ripping if the gravel is in a sandy matrix and does not restrict root growth completely.

Yellow loamy sands with highly acidic subsoils (wodgil) commonly form compaction pans at 15 to 20 cm. However, barley crops seldom respond to deep ripping because root growth (and therefore nutrient and water uptake by the plant) is restricted by the subsoil acidity.

Even on suitable soils, responses to ripping have been least reliable in areas with less than 325 mm annual rainfall. This is probably because the soil may not become moist deep in the soil profile and, ripped or not, the roots have access to all the water available in the profile.

Residual value of deep ripping

The response to deep ripping has been shown to last for up to eight years but at a declining rate. The advantage from ripping declines in time due to:

- re-compaction by traffic;
- natural soil settling;
- the greater removal of nutrients and water by the previous year’s higher yielding crop.

In a wheat:barley:lupin rotation, ripping every second wheat or barley year is a compromise between optimising yield and being able to handle the seasonal ripping program in the limited time available.

When to rip

For maximum yield response, the depth of working must be below the traffic pan and this may mean penetration to at least 30 cm. Moist soil throughout the ripping depth is necessary to reduce power requirement and point wear and to obtain efficient softening.

In the areas of Western Australia where ripping has been widely adopted, responsive soils are usually cropped continuously with cereal and lupin rotations. The time available for ripping is following summer rains, or at the break of the season before sowing. Ripping after seeding (within three days) is common practice and is possible with implements that create little surface disturbance.

Stubble retention

Stubble retention is the general term to describe the range of farming operations which aim to keep some crop residues on the soil surface from harvest up to and after seeding the next crop. It may include retaining all or part of the stubble - livestock can still be an integral part of the system.

The main attraction of retaining stubbles rather than burning them is the reduction in wind and water erosion. Stubble retention is usually seen as a ‘soil saver’ and offers a long term benefit to the industry and the community. Stubble retention is also beneficial because it can prevent, or reduce greatly, the impact of raindrops on the soil surface. But there can also be disadvantages of retaining stubble.

The amount of stubble (Figure 12) and its distribution on the soil surface, or in the soil, determines its effect on soil and crop factors hence its positive or negative contribution to yield.
Total soil cover, or as much as possible, is needed for the best soil protection. The biggest problem with stubble retention is the lack of machinery available in Western Australia that can establish a crop in a good seedbed ready for rapid emergence and growth yet leave the maximum stubble cover, unless the stubble is treated (cut short) during or after harvest.

**Effect of stubble retention on the crop’s environment**

**Benefits**

Stubble retention is likely to:
- reduce wind erosion;
- reduce water erosion;
- increase soil water;
- improve soil structure slightly;
- increase soil organic matter - slowly;
- increase earthworm population.

**Problems**

Retained stubble can affect soil temperature.

The altered temperatures might:
- delay crop germination by one to two days;
- decrease the crop’s early growth rate;
- delay ear initiation slightly;
- increase frost risk;
- alter the germination of weeds;
- decrease germination of legume pasture species.

The other effects of stubble which may reduce yield involve:
- increased disease;
- increased insect populations;
- decreased nitrogen availability;
- possible toxicity to crop when high levels of stubble start to decompose close to seed;
- herbicide inactivation.

**Machinery for stubble retention**

Stubble can be manipulated during harvest and between harvest and seeding the next crop.

The next crop must then be seeded by a machine capable of getting through the remaining stubble, planting the seed correctly and leaving the stubble in the form required to fulfil its chosen function.

**Harvest systems**

If stubble could be left standing, it is likely that there would be few seeder blockages. Enough stubble may be broken off or flattened by harvester wheels, grazing animals and perhaps cultivation or spray machinery to pose problems.

For this reason, there is an emphasis on reducing the lengths of straw in the paddock after harvest by lowering cutting height and chopping straw taken into the harvester.
The addition of chaff spreaders and simple modifications vastly improves the distribution of stubble after harvest. Spreaders that have more flails, longer shafts holding the flails and are faster spinning perform best.

**Post-harvest systems**

The aim of post-harvest modification of stubble is to change the straw length and distribution, or reduce the quantity before seeding.

Techniques to quicken straw decay range from partial incorporation by offset tandem discs and one-way disc ploughs to 'stubble busting' by dragging implements at high speed in hot weather across the stubble to knock it down and break it up; or slashing or mowing the stubble with specially designed machines.

**Seeding**

Most seeders in Western Australia have tine undercarriages that can be blocked by stubble. A tined seeder may need the following features for maximum stubble clearance:

- a coulter system to cut a path through flattened stubble;
- narrow-section rigid tine with maximum (700 mm) vertical clearance;
- narrow points;
- wider tine spacing;
- low pressure press wheels in parallelogram linkage with the tine to cover and gently compact soil over the seed.

In all stubble retention systems there is heavy reliance on herbicides for weed control.

**Selective stubble removal**

While complete ground cover with stubble may sometimes be desirable, the variability in growing conditions means it does not always happen. When it does, machinery has difficulty seeding into it with correct seed placement. Fortunately, the advantages to be gained in wind erosion control do not require complete ground cover so some of the stubble can be removed.

An easy and 'natural' way, is of course, to graze it. Another way is burn it.

**Grazing**

In Western Australia, nearly every stubble retention system must be able to fulfil its objective after some period of grazing, as the value of stubbles for grazing is an integral part of mixed farming systems.

**Burning**

Burning of harvester windrows is a common practice that can achieve the goal of sufficient paddock cover to stop wind erosion only if the windrows burn and the standing stubble does not. Stubble pinwheel rakes improve the reliability of windrow burning by sweeping out loose straw and leaving standing straw behind.
5. NUTRITION

"Firstly, let us take the soil; it is the duty of every farmer to find out the composition of the soil on his holding, both as regards its physical and chemical properties. Then comes the question, ‘How am I to do this? I have no chemical laboratory.’ My answer is ‘Send a fair sample to the country analyst, or, if a member, to the Royal Agricultural Society of England, and the charge for an analysis and report will be amply repaid by the information gained, giving, as it does, an insight into the extent of the capabilities of the soil in respect of the plant food it contains, and, further, enabling the farmer to develop those capabilities by means of applying suitable special manures.

Secondly it behoves the farmer to endeavour to acquire a knowledge of the composition of artificial manures, and also the extent to which various crops are lacking in the different elements of plant food. Having acquired the knowledge, he will be enabled to apply the proper artificial manure to the crop it will be of benefit to; and surely this is far better than indulging in the obnoxious practice of looking through advertisements to find out which manure is cheapest, at the same time utterly disregarding the fact that it may not contain a single useful ingredient."

Extract from Journal of the Bureau of Agriculture, Western Australia, 1896.

PHOSPHORUS

Michael Bolland
South Perth

The need for fertiliser phosphorus

Phosphorus is an essential component of cell membranes, plant genetic material and the energy storage and transfer system that drives chemical reactions in plant cells. Early plant growth is particularly dependent on phosphorus because of the needs for rapid cell division and expansion. Phosphorus deficiency in barley reduces head and grain numbers, which are established early in the development of the crop.

Soils in the agricultural areas of south-western Australia are amongst the oldest and most weathered in the world. They were acutely phosphorus deficient when newly cleared for agriculture and, in the years after clearing new land, regular applications of phosphatic fertiliser were necessary for profitable production. Eventually fertiliser applications over many years have built up soil phosphate levels so that phosphorus deficiency is no longer a major limitation for plant production. On most soils in Western Australia, only enough phosphatic fertiliser now needs to be applied to maintain soil phosphorus levels for profitable production. This is to replace phosphate:

- removed in agricultural products (grain and seed, milk, meat, wool and hides);
- removed by water and wind erosion of soil; and
- that has chemically reacted with the soil or that is incorporated into some stable organic compounds in the soil, and which is no longer available to plants.

Types of phosphatic fertilisers

Plant roots can only take up water-soluble phosphate from the soil. Manufactured phosphatic fertilisers, made by adding acid (sulphuric or phosphoric acid) to rock phosphate, contain most of their total phosphate content in water-soluble form. They are therefore very effective for plant production on all soil types in all environments, and include the superphosphate and ammonium phosphate fertilisers listed in Table 7. These fertilisers are granulated, very stable, and easy to handle and spread. Other nutrient elements, such as copper, zinc, molybdenum, manganese and sulphur, can be incorporated into the granules and applied in the one operation. All the manufactured water-soluble phosphatic fertilisers can be considered as equally effective per unit of phosphorus.
Rock phosphates

Rock phosphates are naturally occurring phosphatic fertilisers. However, they contain negligible water-soluble phosphate. For rock phosphate to be an effective, direct application fertiliser, it must dissolve in the soil. Very few Western Australian soils combine the necessary properties to achieve this to any extent.

In Western Australia, long-term field experiments have shown that, for cereal grain production, from 5 to 100 times as much phosphorus as rock phosphate needs to be applied to produce the same yield as freshly-applied superphosphate. Therefore uneconomical high levels of application of rock phosphate are required.

Barley has a relatively high phosphorus demand, and in Western Australian soils the manufactured water-soluble phosphatic fertilisers listed in Table 7 are the most effective fertilisers for barley production. The most profitable one to use depends on whether nitrogen, or sulphur, or both, are also required, and the cost to purchase, transport and spread the fertiliser per unit of phosphorus, or if required, per unit of nitrogen and sulphur.

Fate of phosphorus applied to the soil as manufactured fertilisers

When the soil becomes wet, the water-soluble phosphate in the fertiliser rapidly, and almost completely, dissolves and moves out of the granule into the soil where it can be taken up by plants. However, water-soluble forms of phosphate are not stable and rapidly react, principally with calcium, iron and aluminium in soil solution and on the surfaces of soil constituents, to form more stable compounds that are insoluble and less available to plants.

The reactions continue, even when the soil is dry, to form even more stable compounds that are increasingly less soluble and less available to plants. In the year of application, usually 5 per cent or less of the applied phosphate is used by plants. Most of the water-soluble phosphate is adsorbed by the soil. Phosphate taken up by plants is either removed in agricultural products, or is returned to the soil as dead tissue, or in the case of grazed pastures, as faeces.

A large number of organisms live in the soil (fungi, bacteria, insects etc.) and they also need and take up phosphate, which is returned to the soil as dead tissues. Most of the phosphate returned to the soil from agricultural plants and soil organisms or grazing animals ends up as organic phosphate in the soil. About 7 to 20 per cent of the total phosphate in freshly-applied fertiliser is not water-soluble. This mostly remains behind in the granule. Consequently, in the years after application, the residues of fertiliser phosphate include adsorbed phosphate, organic phosphate, and the phosphate left behind in the old granules.

All these sources of phosphate release water-soluble phosphate into the soil in the years after phosphate application. Therefore the phosphatic fertilisers not only provide phosphate in the year of application; their residues also provide phosphate for plant uptake in the years after application. This is how the phosphate levels in the soil are built up.

Eventually, enough water-soluble phosphate is released from the fertiliser residues to provide all the plant requirements so that phosphate is in luxury supply and there are no plant yield responses to freshly-applied phosphatic fertiliser. Once soil

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**Table 7. Phosphatic fertilisers available in Western Australia**

<table>
<thead>
<tr>
<th>Fertiliser</th>
<th>% total P</th>
<th>% water-soluble</th>
<th>% of total P that is soluble in water</th>
<th>% nitrogen</th>
<th>% sulphur</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Superphosphate fertilisers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single superphosphate</td>
<td>9.1</td>
<td>7.3</td>
<td>80</td>
<td>Nil</td>
<td>10.5</td>
</tr>
<tr>
<td>Double superphosphate</td>
<td>17.5</td>
<td>14.0</td>
<td>80</td>
<td>Nil</td>
<td>3.5</td>
</tr>
<tr>
<td>Triple superphosphate</td>
<td>20.0</td>
<td>16.0</td>
<td>80</td>
<td>Nil</td>
<td>0 to 1.5</td>
</tr>
<tr>
<td>B. Ammonium phosphate fertilisers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAP</td>
<td>21.8</td>
<td>20.3</td>
<td>93</td>
<td>10.0</td>
<td>Nil</td>
</tr>
<tr>
<td>DAP</td>
<td>20.0</td>
<td>16.0</td>
<td>80</td>
<td>17.5</td>
<td>Nil</td>
</tr>
<tr>
<td>Agrich</td>
<td>12.0</td>
<td>10.6</td>
<td>88</td>
<td>14.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Agras 1</td>
<td>7.6</td>
<td>7.1</td>
<td>93</td>
<td>17.5</td>
<td>16.0</td>
</tr>
<tr>
<td>C. Rock phosphate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground rock phosphate</td>
<td>15.4</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>0.1</td>
</tr>
<tr>
<td>North Carolina rock phosphate*</td>
<td>12.9</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>1.2</td>
</tr>
</tbody>
</table>

* Not yet available in Western Australia
phosphate levels have been built up by applying phosphatic fertilisers over many years, it takes a long time (many years) to run down the soil phosphate levels.

**Calculating the most profitable amount of phosphatic fertiliser to apply**

Yield response to freshly-applied phosphatic fertiliser

Phosphatic fertiliser should only be applied if it is profitable to do so. To determine this, we need to know the relationship between plant yield and the level of phosphatic fertiliser applied in the year of application (Figure 13), hereafter called the yield response curve. For the same soil type and environment, yields vary from year to year because of differing seasonal conditions, so yields are expressed as a percentage of the maximum yield (relative yield), to reduce variations between years.

The yield response curve differs for different soils, and is largely affected by the capacity of the soil to adsorb phosphate. Sandy soils (Soil 1 in Figure 13) have a low capacity to adsorb phosphate, whereas soils with a greater iron and aluminium oxide and/or clay content have higher capacities to adsorb phosphate (Soil 2 in Figure 13). Therefore, relative to Soil 2, a larger proportion of the phosphate applied to Soil 1 is available for plant uptake. As a result, Soil 1 needs less fertiliser phosphate to produce the same relative yield as Soil 2. In Western Australia, simple laboratory methods are used to measure the capacity of the soil to adsorb phosphate. These are the reactive iron content of the soil, and the phosphorus retention index of the soil (PRI). As both the reactive iron content or PRI values for soil increase, so the capacity of the soil to adsorb phosphorus increases.

Yield response curves have been determined for defined soil types and environments in Western Australia. Where any paddock is situated on the relevant response curve can be determined by soil testing.

**Soil testing for phosphate**

For the soil test phosphate calibration, soil test phosphate is measured on soil samples collected during summer (November to March, but usually January to February).

Having obtained a soil test phosphate value for a paddock, the soil test phosphate calibration for that soil type and environment is used to predict the barley grain yield produced by the amount of phosphate already present in the soil, as is shown in Figure 14. The yield predicted from soil phosphate testing in Figure 14 is then transferred to the yield response curve in Figure 13. It is then possible to determine the likely profit (or loss) of obtaining a profitable return from money spent on applying fresh phosphatic fertiliser for the next barley crop grown in that paddock.

Figure 14. The soil test phosphate calibration curves of two soils with differing abilities to adsorb phosphate.

Figure 15 illustrates the simple theory of how this calculation can be made. Figure 15 is produced from Figure 14 by expressing yield and the level of phosphate applied in dollar terms. Yield is converted to dollars by multiplying yield, as tonnes per hectare, by the price paid per tonne for barley. Costs include the price of the fertiliser per hectare and the cost of application.
source of phosphate comes from the seed, until the seedling roots have developed sufficiently to take up significant amounts of phosphate from the soil. Any phosphate deficiency during early growth can greatly reduce grain yields. Consequently phosphatic fertiliser is applied with the seed at sowing. That is, it is drilled with the seed so that the developing plant roots are next to an abundant source of fresh water-soluble phosphate. In this way, proportionally more phosphate is taken up by the plant and less is adsorbed by the soil.

Surface soils in the cereal growing areas of Western Australia frequently dry out between rains during the growing season. Plant roots can not take up nutrients, including phosphate, from dry soil. So placing the phosphatic fertiliser in bands in the soil keeps the fertiliser in moist soil for longer periods, increasing its effectiveness for producing plant yield.

Research has consistently shown that an economic grain yield response to applications of phosphatic fertiliser is unlikely if fertiliser application is delayed for more than 10 days after sowing a cereal crop into wet soil. Also in the cereal growing areas of Western Australia, when phosphate is supplied to the soil, it is unlikely to be leached or moved great distances through the soil unless the soil is cultivated. This is because most soils have a sufficient capacity to adsorb phosphate to prevent it being washed down or through the soil as water flows through the soil. The exceptions are deep, grey sandy soils in higher rainfall (greater than 550 mm annual average rainfall) areas where phosphate has been shown to move down the sandy soil in the years after application. Examples for barley production are the deep Gibson sands near Esperance, the Eradu sandplain soils near Geraldton, and the deep sandy soils at Kojaneerup, north of Albany.

**Seed phosphate**

It is now known that for cereals, including barley, seed of the same size but with a higher concentration of phosphate in the seed will produce larger seedlings and plants, and in some years, up to about 10 per cent increase in grain yields. This is perhaps because in some years the larger seedlings are better able to cope with stress encountered during the growing season, such as drought, disease or pests.

For cereal crops, it has been found that plant yield increases due to seed phosphate occur for phosphorus concentrations in the seed of up to about 0.3 per cent. Thus farmers need to grow the barley they will use as seed for future barley crops on their better soil types that have received large applications of phosphatic fertiliser in previous years. Farmers should also consider applying high levels of phosphate to the barley grown to provide seed for their future crops (i.e. 300 kg/ha single superphosphate).

**Timing and method of application**

Annual plants, such as barley, need phosphate during early growth. As soon as the embryo in the seed starts to germinate, phosphate is required. The initial
NITROGEN AND ROTATION

Mel Mason and Ian Rowland

South Perth

Nitrogen comprises about 16 per cent of the weight of plant protein. It is essential in many other components, including chlorophyll, which gives plants their green colouration and is responsible for carbohydrate synthesis in the plant.

Within the plant, nitrogen can move freely to areas of active growth, which have high demand. Consequently, a symptom of nitrogen deficiency in plants is the yellowing of lower (older) leaves as nitrogen is remobilised and transported from older tissues to younger, actively growing, tissues.

The nitrogen required for successful growth of barley must be supplied either from the soil or as fertiliser. Nitrogen can only be taken up by the plants when it is in an inorganic form, that is ammonium or nitrate.

In the soil, over 90 per cent of the nitrogen is in an organic form, which is not available to the plant until it is mineralised to produce inorganic forms. Organic matter varies in its nitrogen content and its ease of mineralisation, and ranges from readily mineralisable recent crop or pasture residues to older, more stable organic matter which is mineralised slowly.

Mineralisation continues throughout the growing season, providing a continuous supply of nitrogen, which may or may not satisfy the crop requirements, and which will vary with temperature and soil moisture. Mineralisation is stimulated by cultivation. The nitrogen cycle is outlined in Figure 16.

A large part (sometimes all) of the plants' requirement for nitrogen is supplied by the soil. However, where the available soil nitrogen supply is inadequate for optimum yields, the application of nitrogenous fertiliser can be profitable.

The greatest responses to the addition of nitrogen will be obtained in higher rainfall areas on light soils which have not grown legumes recently. The response to fertiliser nitrogen is affected mainly by:

- weather (mainly rainfall);
- soil type;
- recent paddock history (whether a legume has been grown in the rotation).

These factors are included in the Department of Agriculture's recommendations which are based on the results from many trials over the past 40 years. The recommendations are offered as a guide, to be varied in the light of specific local knowledge. Recommendations for wheat can be also used for barley but the cost/price ratio will vary accordingly.
**Soil type**

Heavy soils naturally have more nitrogen and are less prone to leaching losses. Consequently, these soils usually need less nitrogen added (often none) to produce optimum crop yields, unless they have been cropped intensively to non-legume crops.

**Paddock history**

Legume pastures and to a lesser extent, legume crops such as lupins or peas add nitrogen to the soil. This reduces the need for fertiliser nitrogen compared with multiple cereal crops, or where no legumes are grown in the rotation (Figure 17 on following page).

Besides the benefits of nitrogen inputs gained by including legumes in the rotation, they also provide opportunities for controlling grassy weeds, which delay seeding, compete with the barley crop and carry root diseases. Such weed management is also possible if a canola crop is grown before the barley crop.

**Soil moisture**

Moisture stored in the soil at the beginning of the growing season can indicate the likelihood of a good growing season (particularly on heavier soils). Rates of fertiliser should be varied accordingly.

**Nitrogen requirements**

A crop’s requirement for nitrogen will depend on:

- season;
- soil type;
- paddock history;
- soil moisture;
- yield potential.

**Season**

Bigger yield responses will be obtained and more nitrogen will be needed in high rainfall years, because higher yielding crops can be grown. A dry finish to the season will limit yield response.

If high rainfall causes waterlogging then yield and response to nitrogen will also be limited.
Yield potential

For grain with a 2 per cent nitrogen content, 20 kg of nitrogen will be contained in each tonne of barley grown. If the nitrogen harvest index (the proportion of nitrogen in the plant which is contained in the grain) is 75 per cent, then about 27 kg extra nitrogen is needed in the plant. Assuming a recovery of 50 per cent by the plant, an extra 54 kg of nitrogen is needed in the soil for each tonne of grain produced.

If the potential yield increases, then extra nitrogen will have to be supplied either by the soil or by extra fertiliser. Potential yield can be increased by:

- a good early start to the growing season which allows early sowing;
- using an appropriate high-yielding barley variety on a productive soil type;
- effectively controlling weeds;
- being disease-free; and
- ensuring that other nutrients, such as phosphorus, potassium, copper, zinc, molybdenum and manganese are in adequate supply.

Sometimes a paddock has a higher potential because of a higher than normal soil nitrogen level after good legume pasture for a number of years. The requirement for fertiliser nitrogen could be lowered because of the greater supply of available soil nitrogen.

The amount of nitrogen to be applied will be determined by economics. The optimum economic rate depends on the cost of the nitrogenous fertiliser and the price received for barley. Economics are taken into account by the Department of Agriculture when making recommendations.

The Department of Agriculture provides a set of ‘average’ recommendations based on climatic zones, soil type, paddock history and economics. Rates can be altered depending on knowledge of the particular situation.

Soil testing for nitrogen fractions has not proved to be useful. The nitrogen requirement of a crop cannot be indicated by the soil measurement because the response to nitrogen depends greatly on the seasonal conditions that cannot be forecast.

The soil test cannot measure the nitrogen which will be available to the crop at important times during the coming growing season. The soil analysis, however, will give a general idea of the total nitrogen status of the particular site.
Plant tissue can be analysed at various stages of growth and compared with standards, to diagnose deficiency. However, as a predictive test to decide on application rates of nitrogen it is not accurate enough because a subsequent response to fertiliser is still highly dependent on the conditions for the remainder of the season.

Another limitation of the value of a predictive tissue test is that by the time that there is sufficient tissue to test, the optimum time of application is likely to have already passed.

**Sources of nitrogenous fertiliser**

The commonly available sources of nitrogenous fertiliser used on barley in Western Australia are urea, ammonium nitrate (Agran), ammonium sulphate, Agras No. 1, Di-ammonium phosphate or DAP, Agyield and Agrich. (Table 3)

Fertiliser nitrogen is added either as urea, ammonium-nitrogen or nitrate-nitrogen. Urea is quickly broken down by moisture to ammonium-nitrogen. This process is generally complete within about one week, with most breaking down within three days. In most soils the ammonium-nitrogen is oxidised to nitrate by the process of nitrification.

The rate of nitrification of ammonium-nitrogen depends on temperature, moisture and pH. The process is rapid (two to three weeks) in alkaline or calcareous soils and slow in very acid conditions typical of wodgil soils.

With ammonium sulphate or fertilisers based on ammonium sulphate (i.e. Agras or Agrich), the rate of nitrification is generally slower than for urea or ammonium nitrate. The form that the nitrogen is in influences its availability to the plant and its losses from the rooting zone.

If ammonium-nitrogen is applied on the surface, it stays in the surface layer while it is in the ammonium form. If the soil surface dries, this nitrogen is unavailable to the plant. Ammonium-nitrogen is a positively charged ion and is held by excess negative charges on clay, sesquioxides and organic matter in the soil and so becomes immobile.

On the other hand, nitrate-nitrogen is a negatively charged ion and the soil has little or no hold on it. Consequently nitrate is very mobile in the soil and, in sandy soils, can easily be lost by leaching following heavy rains.

In waterlogged conditions, the nitrate-nitrogen can be converted to various nitrogen gases by the process of denitrification and be lost into the atmosphere. Ammonium-nitrogen is not prone to denitrification.

An important factor in deciding which nitrogen fertiliser to use is the cost per unit of nitrogen which can be determined by the formula below:

\[
\text{Price/tonne N} = \frac{\text{Price per tonne of fertiliser} \times 100}{\% \text{ N in the source}}
\]

*(Where N = nitrogen)*

**Example**

\[
\begin{align*}
\text{Urea: Price/tonne N} &= \frac{330}{46} \times \frac{100}{1} \\
&= \$717.39/\text{tonne or 72 cents/kg N}
\end{align*}
\]

where cost of urea (ex works) = \$314/tonne, freight = \$16/tonne

and the nitrogen content of urea = 46 per cent.

The contents of nitrogenous fertilisers are listed in Table 8.

**Table 8. Nitrogen (N) and phosphorus (P) contents of nitrogenous fertilisers**

<table>
<thead>
<tr>
<th>Fertiliser</th>
<th>% N</th>
<th>% P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea</td>
<td>46</td>
<td>0</td>
</tr>
<tr>
<td>Ammonium nitrate (Agran 34-0)</td>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td>Ammonium sulphate</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>Agras No. 1</td>
<td>17.5</td>
<td>7.6</td>
</tr>
<tr>
<td>Di-ammonium phosphate (DAP)</td>
<td>17.5</td>
<td>20</td>
</tr>
<tr>
<td>Agyield</td>
<td>17.5</td>
<td>17.6</td>
</tr>
<tr>
<td>Agrich</td>
<td>14</td>
<td>12</td>
</tr>
</tbody>
</table>
There are sometimes reasons why a source other than the cheapest is used, for example, the convenience of using a compound fertiliser, the effect on disease (an ammonium source where take-all is present) or the effect of an acidifying source such as ammonium sulphate on availability of soil manganese. However, the economics of alternatives should be examined.

The method advisers use to guide decisions on fertiliser choice and rate allows an economic comparison of the sources of nitrogen and phosphorus and mixtures of sources.

**Time of application**

Most responses to nitrogenous fertiliser in Western Australia are the result of an increased number of ears and to a lesser extent, grains per ear.

The response is largely caused by increased tillering, which is determined early in the life of a barley plant. The number of grains per ear is also determined early. Therefore a good supply of nitrogen is needed early in crop growth. Early application is preferred in the production of malting barley because it is more likely to increase yield without raising grain protein levels.

The other consideration is that in sandy soils in higher rainfall areas the application should be delayed three to four weeks. This allows the crop to establish a reasonable root system and avoid large leaching losses.

The best time of application in any one season can vary depending largely on the incidence of leaching rains in relation to time of application. Profitable responses can often be obtained up to 10 weeks after sowing. Late applications are more likely to result in increased grain protein to the detriment of malting quality.

Generally, however, the later the application, the lower the response and the greater the risk of not getting a payable response. Responses to later applications are generally a result of better survival of tillers and to increased photosynthetic area and leaf duration.

**Methods of application**

There are two concerns with nitrogen application:

- the effect of placement of urea on losses to the atmosphere (volatilisation); and
- the effect on germination of placing nitrogenous fertilisers with the seed - a toxicity problem.

**Volatilisation losses of nitrogen**

When urea is moistened and begins to break down, one of the intermediate products is ammonium carbonate which creates alkaline conditions around the urea granule. In the soil there is a balance between ammonium-nitrogen and ammonia. Under normal soil conditions, with acidic pH, most of this nitrogen is in the ammonium form. However, under alkaline conditions more ammonia is produced. If the fertiliser is on the soil surface, some of this ammonia can be lost to the atmosphere in the process called volatilisation.

The greatest loss is when the urea is topdressed onto moist soil and a period with warm temperatures and no rain follows.

Losses can be avoided by covering the urea with soil, say by topdressing immediately before sowing, and when application is followed by rain heavy enough to wash the urea into the soil.

Ammonia losses are difficult to measure directly. Up to 20 per cent may be lost in extreme conditions, but generally losses would be less than 10 per cent. Volatilisation is not a problem with other, more expensive, sources except on alkaline soils.

**Toxicity**

The ammonia produced when urea breaks down is toxic to germinating seedlings, so if urea is drilled close to the seed, it can reduce plant emergence. The severity of the reduction depends on the rate of urea and the conditions at sowing and during germination.

Reductions will be worse with high rates of urea in moist soil but with no follow-up rain for some time. If good rains follow sowing, the effect will be less. If there is only a small reduction in plant numbers, say 10 per cent,
the crop can usually compensate by producing more tillers and grain yields may be unaffected, but higher losses can reduce yields. If more than 30 kg/ha urea is drilled with the seed, yields can decline.

Except in alkaline soils, the other nitrogen sources do not produce toxic ammonia and are therefore less likely to reduce plant numbers or delay emergence. However, where the fertiliser is placed close to the seed in moist soils and there is a long dry period following sowing, plant numbers can be reduced because of the concentrated salt solution around the germinating seed.

Grain protein

Because nitrogen is an essential part of proteins, nitrogen supply is an important determinant of grain protein concentration.

Many factors can affect grain protein, but the relationship between available nitrogen supply, yield response and weather conditions, particularly during grain-fill, is of major importance.

During grain-fill the nitrogen taken up by the plant after anthesis is directed into the developing grain. Also, nitrogen in the plant's vegetative parts is remodelised and transported to the developing grain. Therefore nitrogen supply during the growth of the plant and a late supply of nitrogen to the plant could be important in determining grain protein.

Grain protein depends on the amount of nitrogen available in the plant and the number of grains into which the nitrogen must be distributed. In addition, the protein concentration in the grain depends on how well the grain fills.

Hot, dry conditions during grain-fill reduce carbohydrate deposition in the grain more than protein deposition. Therefore with a hot, dry finish to the season grain protein concentration will be higher than when there is a cool, moist seasonal finish.

The relationship between grain yield response to nitrogen fertilisers and grain protein concentration is shown in Figure 18. In Zone A, where there is a big yield response to added nitrogen, protein concentrations may fall or remain unchanged. In Zone B, where the yield response begins to decline, protein levels begin to increase. Economic rates of fertiliser will fall into Zone B where yields are still responsive to nitrogen but where increases in protein level will be small.

Protein concentrations can be increased substantially by using uneconomic practices, such as over-fertilising on an unresponsive site or by using very late nitrogen applications, when grain yields will be unaffected or only slightly increased.

Soil nitrogen is available to the crop and has the same effect as fertiliser nitrogen. However, there is an additional effect of this soil nitrogen because it provides a supply throughout the season. The nitrogen from this source which is still available well after yield is determined is still taken up by the plants and is important in raising grain protein levels. A ready supply of soil nitrogen is provided by the recent residues of legume pastures and legume crops such as lupins, field peas, faba beans and chickpeas.

Receival standards for malting barley require grain protein levels to be less than 11.8 per cent (dry basis) for acceptance into Malt No. 1 grade. To avoid producing higher protein than this, the crop should not be grown on highly fertile soils following a long...
recent history of legume pastures and legume crops. It would be safer to grow malting barley as a second successive non-legume crop in a rotation. Rates of nitrogen fertiliser in excess of requirements for optimum economic yield should be avoided.

Protein in feed barley grain will be increased by the use of nitrogen fertilisers and by growing the crop after legumes. However, as well as increasing grain protein concentration, high levels of nitrogen will increase sieving percentages.

POTASSIUM

Noeleen Edwards
South Perth

Potassium is a major plant nutrient, required by crops in similar quantities to nitrogen. It is used in many plant processes including photosynthesis, transport of sugars, enzyme activation, maintenance of plant turgor and regulation of stomata. Plants deficient in potassium cannot use other nutrients and water efficiently. They are less tolerant of environmental stresses such as drought and waterlogging. Potassium deficient plants are also less resistant to pests and diseases.

Occurrence

The occurrence of potassium deficiency is determined by soil type, rainfall and management practices.

Soil type

Light textured soils have lower potassium reserves than heavier textured soils. The amounts and type of clay minerals present will have a large influence on the ability of a soil to retain and replenish potassium. Soil testing for potassium measures the potassium that is readily available to plants. This is either water soluble or exchangeable potassium that is adsorbed onto the surface of clay particles and organic matter. In most sandy soils, the potassium concentration is highest in the surface layer where potassium is associated with organic matter.

If clay or gravel occurs in the soil profile, then the potassium level may increase down the profile. However, it cannot be assumed that duplex soils will have high concentrations of potassium at depth. Recent sampling of a range of duplex soils indicates that there is wide variability in the potassium content of duplex subsoils. Even where exchangeable potassium levels do increase at depth, if root growth is restricted by a change in soil texture, then plants may still not obtain sufficient potassium.

Rainfall

Rainfall affects a crop’s requirement for potassium and the extent of leaching losses of potassium. Where the productivity of a crop is restricted by rainfall, the crop’s demand for potassium will be low and deficiency unlikely.

Potassium leaches from sandy soils because they contain less clay and organic matter to retain the potassium in the root zone. Losses are minimal on clays and loams. Sandy soils in high rainfall areas will be the most vulnerable to leaching of potassium.

Management

A crop’s requirement for potassium will increase as yield increases. High yielding cereal crops put large demands on soil nutrient supply, particularly on light to medium soils. While a soil with low potassium levels
may be able to supply sufficient potassium for a low yielding crop, when the yield potential is increased, potassium deficiency may develop. Management factors that can affect crop demand for potassium include cropping intensity, crop yield levels, increased nitrogenous and phosphatic fertiliser rates, sowing date, weed control, timeliness of operations and removal of stubble residues.

Crop requirements for potassium change during the growing season. For cereals, potassium uptake is low at the beginning of the growing season when plants are small, but increases to a peak during late vegetative and flowering stages. The soil must be able to supply the crop’s potassium needs during periods of peak demand.

There does not appear to be a single mechanism by which potassium deficiency limits yield. Restricted potassium supply during early growth stages may be more harmful than later deficiency. Potassium deficiency can affect leaf area, dry matter produced in upper internodes and ears, the number of grains per head or the seed weight. The root system of potassium deficient plants may also be poorly developed.

**Symptoms**

Potassium is very mobile in plant tissues. In deficient plants it is redistributed to new growth so that symptoms appear first in the older leaves. The symptoms of potassium deficiency in barley are similar to those of other nutrient deficiencies, especially nitrogen, but differ slightly in being more restricted to leaf tips and margins initially. Yellowing (chlorosis) and death (necrosis) of the tips of oldest leaves progresses down the margin to give an ‘arrow’ of normal tissue.

In barley, the necrotic areas of the leaf have a distinct flame red appearance. There is premature death of the oldest leaves and the plants may be stunted, with shortened internodes. Stems may be weakened, causing lodging. These symptoms can be difficult to distinguish from those of some leaf diseases. Potassium deficiency can also resemble drought stress.

**Soil levels**

In cereals, soil testing for potassium is only of diagnostic value in identifying deficient areas. The test cannot be used to predict the amount of potassium required by the crop. Information on responses in barley to potassic fertiliser in Western Australia is limited. It is likely that responses will be similar to those of wheat. On sandplain soils with medium to high yield potential, economic responses to potassium are unlikely if the soil test is above 30 ppm.

On duplex soils, responses are more difficult to predict because of variability in the potassium supply from the subsoil. In paddocks with high yield potential, profitable responses in wheat have been measured where the soil test was up to 45 ppm. Where the soil test is above 30 ppm, topdressing test strips of potassic fertiliser onto the crop will help determine whether economic responses can be obtained.

**Treatment**

If a soil test shows that potassium levels are low, a decision about whether to apply potassic fertiliser will depend on soil type, rainfall and the expected yield of the crop. Where the paddock is in a cereal/legume rotation, applying potassic fertiliser in the legume year may increase the amount of nitrogen fixed for the following cereal crop, as well as improving the potassium status of the paddock. In low rainfall areas where the risk of leaching is low, potassic fertiliser can be topdressed following seeding. Potassic fertiliser should not be drilled with the seed as it can severely reduce germination.

In medium rainfall areas, it is better to delay fertiliser application until four weeks after germination, when the plants have developed a root system to take up the fertiliser. Where potassium deficiency is diagnosed in a crop, an economic response to applying muriate of potash will depend on how much growing season rainfall is left for the crop to respond to the fertiliser. Applying muriate of potash at 40 to 80 kg/ha has generally given the most economic responses to potassium in cereals.
TRACE ELEMENTS

Ross Brennan
Albany District Office

Copper

Copper deficient soils are widespread in Western Australia. An estimated eight million hectares, consisting of one-third of south-west Western Australia, has received copper in fertiliser.

Treatment

A single application of 3 to 9 kg/ha copper sulphate (Farmnote 25/88, 'Copper, zinc and molybdenum fertilisers for new land') provides enough copper to account for removal in farm products for more than 100 years with the systems of agriculture now in use in Western Australia.

Re-application has not been necessary in experiments as long as 20-30 years after the initial application - except where the initial application has not been high enough to satisfy the needs of crops grown under extremely high nitrogen supply.

Soil and tissue levels

Soil analysis for copper can easily give erroneous figures and interpretations, but when used correctly, copper extracted from soil by ammonium oxalate can show how much copper the soil is capable of supplying to plants. It can also indicate whether copper fertiliser has previously been applied to a paddock; this is useful if a property changes hands.

When extracted by ammonium oxalate, a copper level of 0.3 parts per million (ppm) or less in the top 10 cm of soil indicates almost certain deficiency for barley; 0.3 to 0.8 ppm copper may be deficient and 0.8 ppm copper and above is almost certainly adequate.

Tissue analysis

Analysis of the youngest emerged blade (YEB) at the five to eight leaf stage, but before flowering, provides the most accurate method of assessing copper status of the barley plant. Provided the sample is not a mixture of copper deficient and healthy plants, the interpretation is relatively simple.

Zinc

Zinc deficiency in plants appears where zinc has not been applied to inherently deficient soils (8-9 million hectares) (Farmnote 25/88) or where plant-available zinc in the soil has declined to inadequate levels.

On light soils, after the initial zinc deficiency is corrected, the zinc supply is maintained at adequate levels for unimpaired plant growth by applying 150 kg/ha or more ordinary superphosphate that contains 400 ppm zinc.

The zinc impurities (60 g/ha) contained in this amount of plain superphosphate will often correct the zinc deficiency in some soils. In these circumstances no further zinc fertilisers have been needed.

However, applying less than 150 kg/ha plain superphosphate or using low-zinc fertilisers such as imported DAP, causes the zinc supply to decline and yields may be reduced.

Treatment

Initial applications of 1 to 2 kg/ha zinc oxide (75 per cent zinc), depending on the soil type (Farmnote 25/88), will correct the deficiency. Zinc sulphate and zinc carbonate are suitable alternative sources to zinc oxide. However, the rate must be adjusted to apply the same rate of zinc as supplied by zinc oxide. Evenness of application is important.

A foliage spray of 1 kg/ha zinc sulphate (23 per cent zinc) in 50 to 100 L of water applied as soon as zinc deficiency is detected will prevent its development. Late foliage sprays applied to crops which are recovering naturally in drier, sunnier conditions may provide little additional benefit.

An annual application of phosphatic fertilisers containing 400 ppm zinc or more is important in maintaining adequate zinc levels. Locally produced phosphatic fertilisers (except plain superphosphate) all contain 600 ppm zinc.
Manganese

Although manganese deficiency in cereals is widely distributed throughout the south-west of Western Australia, it is usually confined to irregular, well-defined patches rarely exceeding 20 ha. With severe deficiency, grain losses may exceed $200/ha.

Cereals have appeared little affected by manganese deficiency on the deep grey sand where the manganese deficiency ‘split seed’ disorder has devastated lupin crops.

Manganese sulphate and superphosphate

On all except highly alkaline soils, 15 kg/ha manganese sulphate mixed with superphosphate and drilled with the seed gives profitable grain increases in all cases where manganese is deficient. Some deficiency may still develop in the most deficient situations.

Topdressed manganese sulphate is usually only half as effective as drilling it with the seed, so twice as much is needed. Coarse-granulated manganese sulphate is markedly less efficient than fine particles or powder, particularly in dry conditions.

Manganese-superphosphate is most profitable where manganese deficiency is known to occur in patches every season.

Foliar sprays

Manganese sulphate at 4 kg/ha in 100 L/ha water is usually very effective on cereals when applied immediately the symptoms show and before plant growth is retarded. Best results are obtained in cool, moist or dewy conditions of early morning or late evening. Two sprays may be needed three weeks apart for complete control of the deficiency.

Follic spraying are useful for treating the usually scattered manganese deficient areas, where the deficiency is noticed for the first time, or on areas where the deficiency occurs in some seasons but not others. It is also useful where manganese-superphosphate or ammonium sulphate drilled with the seed has not fully prevented deficiency.

Spray-grade manganese sulphate, free of impurities, is usually available at a higher price than fertiliser grade.

Ammonium sulphate

Acid-forming nitrogenous fertilisers increase the plant availability of any reactive manganese in the soil. Ammonium sulphate, alone or as a component of Agras, and ammonium nitrate (Agran), have markedly reduced manganese deficiency.

Ammonium sulphate often eliminates manganese deficiency or reduces it to patches which can be spot sprayed. Drilling Agras at 100 kg/ha or more reduces the risk of irreversible growth retardation before a spray can be applied and saves wasting manganese superphosphate on non-deficient areas.

It is the best choice of fertiliser for soil prone to manganese deficiency and where there is no way of establishing the location of deficient patches.

Increased yields in response to the nitrogen content usually more than pay for the Agras even where there is no manganese deficiency.
Boron toxicity

Boron toxicity has been recognised as the cause of a leaf spotting disorder (not associated with leaf disease) in field grown crops of barley in Western Australia.

Observations on crops of Stirling barley grown on soils at Salmon Gums suggest that boron toxicity generally develops in the latter stages of plant growth. This 'spring flush' of boron may be due to roots having come into contact with higher concentrations of boron in the subsoils, and absorbing relatively higher levels of moisture from the subsoils (passively absorbing higher amounts of boron) during spring, when plant transpiration rates are higher and topsoils are generally drier.

However, other environmental conditions may influence the pattern of development of boron toxicity in crops of Stirling barley. Under controlled conditions, moisture stress has been shown to increase the level of boron in the tops of Stirling barley.

Distribution of boron toxicity

In a survey of barley crops in the Western Australian wheatbelt, leaf injury symptoms, characteristic of boron toxicity, were widely distributed in the medium to low rainfall zones. Barley crops with boron toxicity symptoms grew almost exclusively on the duplex soils with alkaline and fine-textured subsoils, which were generally non-saline but probably sodic. Although these soils comprise nearly 1.5 million hectares of agricultural land, the distribution of boron toxicity within affected crops was very uneven.

The incidence of boron toxicity appears to vary from season to season. It is likely that yield losses caused by boron toxicity are greatest in low rainfall years when boron susceptible varieties are unable to extract moisture from a boron toxic subsoil. Observations at Salmon Gums indicate that Stirling barley has yielded up to 4 t/ha in a wet year despite exhibiting spotting due to boron. In contrast Stirling yields less than the later maturing, boron tolerant variety Skiff in dry years. Also, barley varieties differ markedly in their susceptibility. Stirling is the most susceptible, followed by Forrest, then Clipper, then O'Connor. Skiff is the most tolerant. This may explain why boron toxicity symptoms became more noticeable since the release of Forrest and Stirling barleys.

It is likely that the only available solution to the problem will be to avoid growing the more susceptible varieties where boron toxicity symptoms have been observed. Boron levels in the grain can be a useful indicator of toxicity. Levels of 3 ppm or more indicate that the crop was grown on a soil with the potential to develop boron toxicity problems.

Further reading

Farmnote 10/85, 'Boron toxicity in barley'. Western Australian Department of Agriculture.

Sulphur

Sulphur deficiency has rarely been diagnosed in Western Australia because of the widespread use of single superphosphate containing 10-11 per cent sulphur. Deficiencies of sulphur are most likely to occur on the deeper sandy soils of the wetter margins of the wheatbelt, in situations where triple super (1.5 per cent sulphur) or DAP (1 per cent sulphur) have been used for several years.

Symptoms

With low nitrogen, sulphur deficient plants have pale younger leaves, growth is retarded and maturity delayed. Where nitrogen has been applied, the sulphur symptoms become more severe. The entire plant becomes lemon-yellow and stems redden. Symptoms vary from nitrogen deficiency where old leaves are severely affected first.

Deficiency most often occurs in the wetter years and progressively becomes more severe with successive years when using fertilisers with a low sulphur content.
**Treatment**

Sulphur deficiency can be avoided by using sulphur-containing phosphatic fertilisers at rates which supply 5 to 10 kg sulphur/ha. These sulphur containing fertilisers need to be used in rotation with DAP or triple super in a fertiliser strategy.

**Diagnosis**

Tissue tests can act as a rough guide; 0.2 per cent sulphur in younger leaf tissue is the critical level used for many crops, but often the nitrogen to sulphur ratio (N/S) is also a valuable guide. A ratio of greater than 19:1 often indicates sulphur deficiency.

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**SOIL ACIDITY AND BARLEY PRODUCTION**

**Perry Dolling**

Katanning District Office

In the medium rainfall region of Western Australia, many light textured soils were slightly acidic before they were cleared. With the introduction of agriculture, these soils are becoming more acidic because of:

- leaching of nitrogen;
- removal of nitrogen in produce (grain, seed, meat) from paddocks.

Nitrogen inputs can come from legumes or applied fertiliser. When produce is removed it is like removing lime, leaving the soil more acidic.

Some of these soils are now acidic enough to affect barley production. Barley is more sensitive than other cereals to soil acidity.

**Causes of yield loss**

As the soil becomes more acidic, aluminium availability increases and it can become toxic to plants. Barley is particularly sensitive to aluminium toxicity. By contrast, some nutrients such as phosphorus and molybdenum can become less available as acidity increases and they could become deficient.

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**Measuring soil acidity**

Soil pH is a measure of how acidic the soil is: the lower the pH, the higher the acidity. Soil testing laboratories use a number of methods to measure pH, usually making the measurements on a suspension of soil in water or in a calcium chloride (CaCl₂) solution. The CaCl₂ method is a more reliable measure of soil acidity. Add 0.7 of a unit to roughly convert pH measured in CaCl₂ to a pH measured in water.

**Managing soil acidity**

Follow the steps below to reduce the yield losses of barley caused by soil acidity.

- Measure the pH of the topsoil (0 to 10 cm), especially of light textured paddocks, before growing barley.
- If the pH in CaCl₂ is below 4.5 and previous barley crops have performed below expectation, apply lime before growing barley or grow tolerant species and sow barley on paddocks with a higher pH.
- If the pH in CaCl₂ is 4.5 to 4.7, then remeasure the soil pH in two to three years time, since acidification will continue and pH will decrease further. If the pH in CaCl₂ is above 4.5, soil acidity will not affect production of barley.

**Solutions to the problem**

There are two main solutions to soil acidity - applying lime and using tolerant crops.
Lime

Lime incorporated in the topsoil can correct soil acidity and increase the grain yield of barley (Figure 19). High quality lime at 1 t/ha will increase the soil pH by 0.3 to 0.7 of a unit. The effect will last about 10 years.

![Graph showing the response of barley to lime at two sites both of which had a pH of 4.1](image)

Lime must be well mixed with the soil to be effective. Cultivation before seeding rather than direct drilling will give best results.

Avoid applying lime at more than 2.5 t/ha, since too much lime can induce trace element deficiencies, particularly zinc and manganese.

Response to lime can still be obtained on paddocks that have acid subsoils (pH in CaCl₂ of 3.9 to 4.5 in the 10 to 30 cm layer). Lime does not readily leach, so applying lime to the topsoil will not rapidly correct acid subsoils, although maintenance applications may gradually leach into the profile.

Tolerant species

Many cereals are more tolerant than barley to soil acidity. If your paddock is acid then you could grow tolerant crops rather than growing barley. This however, does not correct the problem and acidification will continue.

Most varieties of wheat, oats and triticale are more tolerant to soil acidity than barley. However, the wheat varieties Aroona and Cranbrook are sensitive to soil acidity (Figure 20). Tolerant species can overcome the effects of acid subsoils to some extent.

All commercial barley varieties are equally sensitive to soil acidity. Barley varieties more tolerant to soil acidity do occur, but they are not agronomically suitable at this stage.

![Barley and Wheat Varieties Graph](image)
6. WEED CONTROL

David Bowran

South Perth

Introduction

When developing a weed control program for use in crops it is vital to plan ahead so that all methods available can be considered or used. It is also important to know the weed species present, their density, area involved and distribution over the paddock. Different weed species have different competitive abilities and the economic threshold for control varies between weed species.

The cost of the proposed control measures should be considered in relation to the expected benefit from the control of the weeds. A short-term or long-term view may be taken. The short-term view considers costs and benefit in the current year, while the long-term view considers implications for future years. The short-term approach follows the concept of treating weed infestations while the long-term approach is based on managing weed populations. The long-term approach is favoured because it takes into account the pool of weed seeds in the soil that will result in reinfestation of future crops.

The threshold of weed numbers is lower in a continuous cereal-lupin rotation than in a cereal-pasture rotation. In a continuously cropped paddock, control of early weed competition and prevention of seed set from late germinated weeds are both important. When a cereal crop is followed by pasture, emphasis can be placed on reducing early weed competition rather than preventing seed set. Weeds which germinate later in the crop are less competitive and could be left untreated.

Having decided on the period and scale of the weed control measures to be taken, the manager must also define the actual problems to be overcome and put them in order of importance before any advance can be made towards their solution. Only then can the project be costed so that reasonable limits may be set on expenditure and reasonable goals set for the expected benefit.

No one weed control method is normally sufficient by itself for an effective weed control program at reasonable cost. Instead, a combination of agronomic, biological and chemical methods will usually be found to be the most efficient and cost-effective. In recent years there has been a trend towards over-reliance on the use of selective herbicides for weed control at the expense of traditional cultural methods such as:

- grazing sheep or cattle,
- fallow,
- light autumn cultivation to ensure even weed germination,
- crop and pasture rotations,
- non-selective herbicides (spray-topping pasture), and
- delayed seeding and cultivation.

This dependence on herbicides has led to the development of herbicide resistant weeds, especially annual ryegrass, and may have large implications for the sustainability of continuous cropping.

In cereal crops, the potential yield is determined by the number of tillers per plant, the number of grains per head and the grain weight. Competition for nutrients is critical in determining the first two factors and usually occurs in the first two to five weeks after crop emergence, while grain weight is determined at a much later stage in the crop's life. Yield benefits from weed removal are greatest when competition for nutrients is eliminated in that first five-week period.

There is likely to be a lower yield benefit if weed control is delayed beyond the early crop tillering stage unless moisture competition becomes critical at the grain filling stage. To gain the full yield response to weed control it is therefore critical that weed competition be eliminated as early as possible in crop development.

Many farmers recognise that controlling weeds during the legume crop or pasture phase of the rotation will reduce the cost of weed control in the cereal crop. However, the development of herbicide resistant weeds may limit these options.

Although fallow, cultivation and delayed seeding have economic and environmental disadvantages, they may be necessary if a cropping program is to be continued after the development of herbicide resistance.
The following sections deal with the use of herbicides in a more specific manner to control weeds in barley crops with comments where applicable on the role of non-herbicidal treatments. The more general comments on non-chemical methods of weed control are to be found in Chapters 3 and 4 of ‘The management of agricultural weeds in Western Australia’ (Bulletin 4243, Department of Agriculture, Western Australia).

**Weed control with herbicides**

**Transplanted weeds**

Some weeds, and especially capeweed, germinate readily after late summer-early autumn rains and can make rapid root growth despite producing little above-ground growth. If conditions are wet after the soil is cultivated, or if inadequate rates of knock-down herbicide are used, these plants will survive as transplants. Failure to control these plants before seeding can leave transplants in the emerging crop. These are frequently accompanied by a fresh germination of weed seedlings. Transplanted weeds are extremely competitive and low rates of herbicide will be ineffective.

Research at Wongan Hills Research Station suggests that capeweed seedling density would need to be some two and a half times higher than transplants to cause the equivalent percentage drop in yield. For example, 25 seedlings or 10 transplants per square metre cause a 15 per cent drop in yield.

**Prevention and control of transplanted capeweed**

Once transplanted weeds are present in the crop, options are usually limited. In some cases it may even be advisable to use a knock-down herbicide and resow the crop. Fortunately capeweed has more control options than many other weeds.

**Before seeding**

- Spray Seed® (paraquat + diquat) at 1.0 L/ha is not as effective as 2.0 L/ha and a shorter delay (less than two days) between spraying and seeding will improve results.
- Addition of diuron to Spray Seed® improves control. However, some diuron formulations can react with diquat or paraquat based products to form deposits which may block filters or nozzles. High rates of diuron before seeding may damage barley on lighter soil types.
- Glyphosate (450 g/L) at 500 mL/ha is usually satisfactory if weeds are not drought stressed.

- If no grasses are present, diuron + 2,4-D amine is a valuable option.

**After seeding**

- Diuron applied immediately after sowing, gives good control, but is not as good as pre-sowing treatments. The addition of Lontrel® (clopyralid) to diuron can increase the efficacy of diuron substantially.
- Terbutryn, (for example, Igran®) is not as good as diuron.
- Post-emergence sprays give control at high rates but are costly. Lontrel® is safe to the crop from very early after crop emergence and is the best post-emergence option.

Delayed application of herbicides allows weeds to continue growth and compete with crops. In particular, the diameter of capeweed plants can be expected to double in less than two weeks once rosettes begin to form. Work at Narrogin showed that delaying treating transplanted capeweed could cost 100 kg/ha/week in reduced yield.
Control of other transplanted weeds

Other weeds which often become transplants into barley crops include doublegeese, wild radish, erodium, sorrel, annual ryegrass, barley grass and silver grass. Broad-leaf herbicides such as Ally® (metsulfuron) and Glean® (chlorosulfuron) will usually give adequate control of a range of broad-leaved species even at larger sizes. Grasses are often very difficult to control as transplants as few selective herbicides are available. Ryegrass (and especially herbicide resistant ryegrass) is very difficult to control and in severe situations it may be necessary to use a knock-down herbicide such as glyphosate and replant the crop.

Pre-emergence weed control

This section deals with selective, residual herbicides that are incorporated before or during seeding. These include trifluralin, Stomp® (pendimethalin), Yield® (oryzalin plus trifluralin), Stampede® (trifluralin plus tri-allate), Avadex BW® (tri-allate), and metribuzin.

Barley, brome and silver grasses

Silver grass, brome grass and barley grass are often a problem in emerging crops after early seeding or with crops planted hastily on the first or second rains. Options for control include:

- delayed seeding,
- shallow cultivation - tickle.

None of the pre-emergence herbicides gives totally satisfactory control of these grasses. However, trifluralin, Yield®, Stomp®, metribuzin and their various mixes will give some control. Improved control gained by mixing these products may be offset by increased potential crop damage. Because barley is generally far more competitive crop species with weeds, these treatments tend to be more effective than when used in wheat. Barley tolerates metribuzin far more readily than wheat, and this opens up wider options for controlling these weeds as metribuzin can give levels of efficacy on these weeds equivalent to trifluralin on ryegrass.

Barley and brome grass have been successfully removed from cereals as they emerge, using low rates of paraquat. Timing is critical as barley beyond the first half leaf emerged may be seriously damaged. The crop will need to be re-sown if the technique fails and the crop is killed.

Annual ryegrass and wild oats

Pre-emergence herbicide options for the control of ryegrass include the dinitroaniline herbicides (trifluralin, Stomp® and Yield®). Where ryegrass and wild oats occur together Stampede® may be used. Where wild oats occur alone, Avadex BW® (tri-allate) can be used. Metribuzin will provide some control of these weeds but is most effective when used in mixtures, especially with trifluralin.

The dinitroaniline herbicides were widely used in the 1970s but have the disadvantages of lower efficacy (70 to 75 per cent) and the need for soil incorporation. Many farmers now use post-emergence herbicides such as Hoegrass® for control of ryegrass. With the development of resistance in ryegrass populations to Hoegrass® and the sulfonylureas (e.g. Glean®, Siege®, Ally®), there has been a resurgence of interest in trifluralin for the control of ryegrass.
Trifluralin

The advantages of trifluralin are that it is relatively cheap and that it is a pre-emergence herbicide that can be tank-mixed with knock-down herbicides. Points to note are:

- Trifluralin is volatile and must be incorporated in the soil within four hours. Losses due to volatilisation are greatest at high temperatures.

- For best results with trifluralin, the paddock should be either pre-worked or stubble residues must not cover more than 25 per cent of the soil surface. Excessive amounts of stubble will make good incorporation very difficult, if not impossible, unless culti-trash seeders are used.

- Trifluralin should be incorporated evenly in the top 2.5 cm of soil. The barley must be sown under the trifluralin layer. Barley sown in the trifluralin layer will either fail to emerge or if it emerges it may have stunted root systems, poor subsequent growth, or may lodge later in the season. This factor makes it important to consider seeding equipment used. As a safety margin it is wise to suggest a 10 per cent increase in seeding rates if trifluralin is used.

- As an alternative to incorporation by sowing, trifluralin can be applied immediately after sowing and incorporated by prickle harrows such as Phoenix harrows. This will leave a very uniform, shallow layer of herbicide, but losses by volatilisation will be greater than with a full incorporation.

Trifluralin is registered for application and incorporation one or two weeks before sowing. However, many farmers have successfully incorporated trifluralin at sowing, by maintaining good depth control and adequate seeding rates.

The level of control of ryegrass will vary but, generally speaking, 75 per cent control could be expected. This makes trifluralin an option where ryegrass densities are likely to be low to medium.

Yield®

This formulation contains two dinitroaniline herbicides, trifluralin and oryzalin. Unlike trifluralin, oryzalin is not volatile but because the trifluralin is present Yield® must be treated in the same way as other trifluralin based products.

Stomp®

The active ingredient in this herbicide is pendimethalin. Like oryzalin, it has lower volatility and water solubility than trifluralin. Consequently it is important to achieve uniform incorporation in the top 2.5 cm of soil if good weed control is to be achieved. Like trifluralin, crop damage will occur if seed is sown into the treated band.

Avadex BW ®

The development of diclofop resistance in wild oats has resulted in renewed interest in tri-allate. In the past, farmers have been put off using tri-allate because of the soil incorporation requirements. According to the existing label, tri-allate must be harrowed into the soil immediately after application. However, many farmers around Australia have been getting good results with tri-allate without strictly following the incorporation instructions. The following are characteristics of tri-allate, the active ingredient of tri-allate may explain why this is so:

- the response to incorporation is because of the need for moist soil to activate tri-allate;
- tri-allate is bound on soil particles and is stable to volatilisation from dry soil for up to 28 days at temperatures of up to 50°C and is not broken down by sunlight.

On application to soil, tri-allate becomes bound to soil colloids and vaporises in the presence of water. It is active in a soil moisture range from 5 per cent above permanent wilting point to 5 per cent below field capacity. The only significant losses are likely to occur from a moist soil surface.

Losses of tri-allate from a dry soil surface are expected to be low and a delay in incorporation of up to 24 hours is unlikely to significantly reduce herbicide activity. This will enable more flexibility in the seeding operation.

A maximum of 25 per cent ground cover of crop residues can be tolerated. Rain will wash tri-allate off stubble on to the soil.

Metribuzin

This herbicide works in a similar manner to simazine and as such it requires adequate soil moisture to ensure it is active. However, it
is very water soluble and on sandy soils may be leached from the root zone before it can be taken up by weeds. Morrell barley is sensitive to metribuzin on duplex soils and metribuzin should only be considered a last resort for this variety.

**Early post-emergence weed control**

(crop emergence to five leaves on main stem - Z10-15)

In considering early post-emergence treatments to any crop it is important to bear in mind timeliness of application, rate of herbicide and crop effects. Herbicides are available for most broad-leaved weeds in-crop but of the grasses, only wild oats and annual ryegrass have herbicides registered for in-crop weed control.

**Grass weeds**

*Barley, brome and silver grasses*

Of the grasses found growing in cereal crops, brome grass, barley grass and silver grass cannot be controlled effectively with currently registered herbicides. These three weeds should be dealt with in the previous phase of the rotation or with pre-seeding options such as cultivation or knock-down herbicides.

Where these weeds emerge before crop emergence, a knock-down treatment such as Spray.Seed® can be used to burn off the small grass seedlings, but it is important to ensure that no crop emergence has occurred (do not use glyphosate based knock-downs in this way). In barley, low rates of metribuzin can provide some selectivity and may be a useful option if the crop has emerged and weeds are still small.

**Annual ryegrass and wild oats**

Annual ryegrass and wild oats are two of the most competitive weeds of cereal crops. The conditions of cereal cropping favour their germination and vigorous growth, which when combined with their high seed populations from preceding crops or pasture, can often lead to very large reductions in potential yield. Both species exhibit staggered germination which often leads to very poor cultural control. Because of their strong competitive effect with the crop, it is desirable to control these weeds in the first few weeks after crop emergence if maximum benefit is to be obtained from the use of a post-emergence herbicide. The major herbicides for control of these two grasses are shown in Table 9.

**Drake**

Drake is a grass weed which looks very similar to annual ryegrass at the seedling stage, but can be identified at maturity by its larger ears and bigger seeds (which makes separation from the cereal grain difficult). Drake is an unwanted contaminant of grain because of its potential to carry ergot - a fungal structure - which can poison products made from the contaminated grain. Drake also tends to have a slower germination than ryegrass. In glasshouse experiments, the herbicides registered for ryegrass have all been found to control drake. These are diclofop methyl, tralkoxydim and chlorsulfuron.

### Table 9. Herbicides registered for the post-emergence control of annual ryegrass and wild oats in cereals

<table>
<thead>
<tr>
<th>Weed</th>
<th>Herbicide</th>
<th>Timing (no. leaves)</th>
<th>Comments on use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual ryegrass</td>
<td>diclofop-methyl</td>
<td>1-4</td>
<td>Most active herbicide for this weed in cereals</td>
</tr>
<tr>
<td></td>
<td>chlorsulfuron</td>
<td>up to 3</td>
<td>Generally gives good control of small weeds but sometimes only provides suppression for 2-4 weeks</td>
</tr>
<tr>
<td></td>
<td>tralkoxydim</td>
<td>1-3</td>
<td>Weakest herbicide available for annual ryegrass and is best used where wild oats is major weed</td>
</tr>
<tr>
<td>Wild oats</td>
<td>diclofop-methyl</td>
<td>1-4</td>
<td>Less active on wild oats than on ryegrass. Tillered plants may be poorly controlled</td>
</tr>
<tr>
<td></td>
<td>tralkoxydim</td>
<td>1-6</td>
<td>Excellent wild oat control on plants of most sizes</td>
</tr>
</tbody>
</table>
Canary grass

Canary grass is the another grass weed which infests cereal crops and is usually confined to heavier red soils. While not common as a weed, in some situations it may be of sufficient density to justify control. The herbicide tralkoxydim (Grasp®) is registered and provides good control. DiCofop methyl may give suppression if applied at the one leaf stage.

Broad-leaved weeds

The number of broad-leaved weeds found in crops is generally much larger than for grasses. However, in general there are only a few which are sufficiently widespread or competitive to warrant a discussion. These more common broad-leaved weeds will be discussed below. However, some weeds are of significant local importance (soursob, sorrel, dock, fumitory, self-sown legumes, wireweed) and for these and less common weeds, referral to the ‘Cereal, pea and lupin weed spraying charts’, published annually by the Department of Agriculture, will provide guidance to what herbicides can be used. Table 10 gives an indication of the herbicides used on the major broad-leaved weeds in Western Australia.

Capeweed

Capeweed is probably the most common broad-leaved weed of cereal crops given its widespread occurrence in pastures and the relative ease with which its seeds can be wind blown between paddocks. Seedling capeweed Incrop is readily controlled by a wide range of products with mixtures of diuron + MCPA and

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Capeweed</th>
<th>Doublegee</th>
<th>Wild Radish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bromoxynil</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Bromoxynil + diflufenican</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Bromoxynil + MCPAe</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Bromoxynil + MCPAe + dicamba</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Chlorsulfuron</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Clopyralid</td>
<td>X</td>
<td>s</td>
<td></td>
</tr>
<tr>
<td>Dicamba</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Diuron + 2,4-Da</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>MCPA amine, ester</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Metsulfuron</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Terbutryn + MCPAa</td>
<td>X</td>
<td>x</td>
<td>X</td>
</tr>
<tr>
<td>Metosulfam</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Flumetsulam</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>2,4-D amine, ester</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

X = good control at rates appropriate for weed size
x = good control at highest rates on small weeds
s = suppression only; may only kill very small weeds

2,4-D providing very cost effective control. Clopyralid is a very effective herbicide for capeweed for both seedlings and transplants. It is slower acting than bromoxynil or diuron based mixtures but has advantages in excellent crop safety and in being compatible with most other broad-leaf and grass weed herbicides. Terbutryn based herbicides are most effective on seedling capeweed but have the effect of causing crop yellowing in some situations.

Doublegee

Doublegee infestation of barley is generally on a lesser scale than for capeweed, but its ability to exhibit both dormancy and staggered germination can pose problems with regard to optimum timing of application. Both metsulfuron and diuron + MCPA have proven to be cost effective herbicides for small seedling doublegee, with metsulfuron the herbicide of choice where large or transplanted doublegee occur. It is important to remember that seed production can begin at relatively early growth stages (as few as four leaves) especially on stressed or later emerging plants, and that if control aims to reduce seed production, delays in application to ensure adequate emergence may be counterproductive in some situations.
Wild radish (and other wild crucifers)

The wild crucifers and wild radish in particular continue to be some of the most widespread weeds of cereal crops despite 45 years of chemical control. Most weeds of this family exhibit strong dormancy and staggered germination characteristics which make their control difficult.

The phenoxy herbicides 2,4-D and MCPA have been widely used for wild radish control since the late 1940s, but have taken a lesser role in more recent years as safer products with earlier application timings have been developed. Both sulfonylureas such as chlorosulfuron and new triazole pyrimidine herbicides such as Eclipse® and Broadstrike® are effective wild radish herbicides with good capacities to kill quite large plants when used in a post-emergence role.

Combinations of MCPA ester or amine with other herbicides (bromoxynil, diflufenican, diuron, terbutryn) are all generally effective if the wild crucifers are small but some consideration of application timing is usually necessary. Bromoxynil + diflufenican combines two effective wild radish herbicides which provides for good crop safety and so allows for earlier application than with the MCPA mixture herbicides. For best weed control with bromoxynil + diflufenican it is necessary to ensure that rates suit weed size.

Crop damage with herbicides on barley

A number of herbicides registered for use in barley have been shown to reduce yield in particular varieties. The extent of the yield reduction varies with rate of application and environmental conditions. Stirling can be quite sensitive to chlorosulfuron if it is growing under high soil moisture conditions, is deficient in trace elements, or exposed to root disease such as ryzocotnia.

Yagan and Morrell have both shown substantial yield losses to chlorosulfuron application even under favourable conditions. Yagan is moderately susceptible to tralkoxydim and metsulfuron, while Morrell can be severely damaged by metribuzin at higher rates. The reductions in yields of different varieties obtained with the most commonly used post-emergence herbicides are provided in the Crop variety sowing guide for Western Australia published annually by the Department of Agriculture.
Late post-emergence weed control

(pseudo stem elongation to grain maturity)

To avoid crop yield losses from competition, weeds must be controlled early in the season. However, weeds may appear late in the crop because of:

- late germination of weeds;
- failure of earlier herbicide treatments;
- lack of a control method.

It is important that these weeds are prevented from maturing and setting seeds within the crop.

Harvested grain that is contaminated by weed seeds and other plant fragments may be unsaleable. Strict grain receival standards for levels of weed seed contamination (and unmillable material) have been defined by grain marketing authorities.

Weed seed contamination in grain can be reduced by improving the screening capacity of the header or by delaying harvest until weed seeds have been shed. These techniques allow large numbers of weed seeds to return to the soil and will make weed control more difficult in future crops. There is also a chance that seeds of herbicide resistant weeds will be returned to the field. Trailing bins behind the header have been designed to collect and remove weed seeds from the field.

An integrated approach to weed control will ensure that low numbers of seeds are carried over from year to year. Thousands of seeds may be produced by a single plant. While a small infestation of weeds late in the season may not reduce grain yields, the weed seed bank may be substantially increased. Weed seeds returned to the field may create a problem for many years, particularly when the seeds have a high level of dormancy. Late post-emergence chemical control will reduce weed seed contamination of the harvested grain sample and reduce weed seed carryover into the following season.

The phenoxy herbicides (2,4-D and MCPA) are commonly applied as late post-emergence treatments and to reduce the seed set of wild radish, wild mustard, wild turnip and lupins. These herbicides must be applied before booting and preferably no later than full flag leaf emergence otherwise serious yield losses may occur. Combinations of 2,4-D ester and Ally® have caused large yield reductions and should not be used. Herbicides registered for the post-emergence control of the major broad-leaved weeds in cereal crops in Western Australia are listed in Table 10.

The benefits of late post-emergence weed control are reductions in:

- weed seed contamination of the harvested grain sample;
- the need for seed cleaning;
- seed-set and seed carry-over;
- weed infestations in future crops.

Trade and chemical names of herbicides

<table>
<thead>
<tr>
<th>Trade names</th>
<th>Chemical name</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,4-D</td>
<td>2,4-D</td>
</tr>
<tr>
<td>Ally®</td>
<td>metsulfuron</td>
</tr>
<tr>
<td>Avadex®</td>
<td>tri-allate</td>
</tr>
<tr>
<td>Broadstrike®</td>
<td>flumetsulam</td>
</tr>
<tr>
<td>Brodal®</td>
<td>diflufenican</td>
</tr>
<tr>
<td>Bromoxynil</td>
<td>bromoxynil</td>
</tr>
<tr>
<td>Diggrass®</td>
<td>diclofop methyl</td>
</tr>
<tr>
<td>Eclipse®</td>
<td>metosulam</td>
</tr>
<tr>
<td>Glean®</td>
<td>chlorosulfonyl</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>glyphosate</td>
</tr>
<tr>
<td>Gramoxone®</td>
<td>paraquat</td>
</tr>
<tr>
<td>Grasp®</td>
<td>tralkoxydim</td>
</tr>
<tr>
<td>Hoegrass®</td>
<td>diclofop methyl</td>
</tr>
<tr>
<td>Igran®</td>
<td>terbutryn</td>
</tr>
<tr>
<td>Intrel®</td>
<td>clopyralid</td>
</tr>
<tr>
<td>MCPA</td>
<td>MCPA</td>
</tr>
<tr>
<td>Metribuzin</td>
<td>metribuzin</td>
</tr>
<tr>
<td>Nugrass®</td>
<td>diclofop methyl</td>
</tr>
<tr>
<td>Reglane®</td>
<td>diquat</td>
</tr>
<tr>
<td>Roundup®</td>
<td>glyphosate</td>
</tr>
<tr>
<td>Siege®</td>
<td>chlorosulfonyl</td>
</tr>
<tr>
<td>Spray-Seed®</td>
<td>diquat+parquat</td>
</tr>
<tr>
<td>Stampede®</td>
<td>trifluralin</td>
</tr>
<tr>
<td>Stomp®</td>
<td>tri-allate</td>
</tr>
<tr>
<td>Surfalan®</td>
<td>pendimethalin</td>
</tr>
<tr>
<td>Trifluralin</td>
<td>oryzalin</td>
</tr>
<tr>
<td>Yield®</td>
<td>oryzalin + trifluralin</td>
</tr>
</tbody>
</table>
7. INSECT PESTS OF BARLEY

Michael Grimm
Albany District Office

The value of crop protection depends on how good the crop is. If a barley crop has been established using the best agronomic practices and is expected to produce close to its yield potential, then:

- the risk of seedling pests will have been minimised;
- the risk of losses from aphids has increased;
- controlling armyworm will be more difficult.

Pest occurrence and risk of damage to crops

The insect pests of barley in Western Australia are listed in Figure 21, together with the periods when they can occur. Seasonal factors, rotations, paddock management and planting time will influence the risk of loss from particular pests. The name of the game is risk management. You can reduce the risks of loss from seedling pests by paddock management. Aphids and armyworm are mobile and are more dependent on seasonal factors. It is important to know the conditions leading to high or low risk for these pests.

As a general rule, the returns from using insecticides to control pests depend on how good the crop is, and that depends on how well the crop is set up in the first place. Table 9 (on the following page) summarises the low and high risk factors for pests in barley. It is clear that the best practices used to eliminate root diseases, grasses and weeds will reduce seedling pests risks, and establish a crop with sufficient yield potential to pay for control of aphids and armyworm if necessary.

Seedling pests

Damage from seedling pests is a good indicator of poor cropping practice. If all the recommendations given elsewhere in this book for setting up crop paddocks to eliminate root diseases, grasses and weeds (including summer weeds) are followed, most of the risks from pests should also have been minimised.

Weed-free lupin, canola or wheat stubbles should be virtually free of seedling pests. Pasture paddocks may present higher risks, especially if they are only spray-topped the spring before cropping. One or two years of manipulation to provide legume dominant pastures is preferable. Control of redlegged earth mite, lucerne flea and bluegreen aphids should be part of the preparation of pastures in the year before cropping. This will maximise legume growth and seed production going into the crop cycle.
**Table 9. Risk factors associated with insect pests of barley**

<table>
<thead>
<tr>
<th>PEST</th>
<th>LOW RISK</th>
<th>HIGH RISK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Webworm</td>
<td>Grass free paddock</td>
<td>Grass residues</td>
</tr>
<tr>
<td></td>
<td>Lupin, canola, wheat stubble</td>
<td>Dense grass</td>
</tr>
<tr>
<td></td>
<td>Early planting</td>
<td>Germination</td>
</tr>
<tr>
<td></td>
<td>Three week, grass free fallow</td>
<td>Late planting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct seed into grassy pasture</td>
</tr>
<tr>
<td>Cutworm</td>
<td>Low broad-leaved weed count</td>
<td>Direct seed into weedy pasture</td>
</tr>
<tr>
<td></td>
<td>No summer weeds</td>
<td>Established summer weeds</td>
</tr>
<tr>
<td>Desianta</td>
<td>Grass free paddock</td>
<td>Early germinated grasses</td>
</tr>
<tr>
<td></td>
<td>Sand deeper than 30 cm</td>
<td>Shallow sands over gravel/clay</td>
</tr>
<tr>
<td></td>
<td>Summer weeds controlled</td>
<td>Grassy pasture in previous spring</td>
</tr>
<tr>
<td>Redlegged</td>
<td>Mites controlled in previous spring</td>
<td>Previous spring</td>
</tr>
<tr>
<td>earth mite</td>
<td>Low capeweed</td>
<td>flush growth of capeweed</td>
</tr>
<tr>
<td></td>
<td>Clean stubble paddock</td>
<td>and clover with high mite counts</td>
</tr>
<tr>
<td>Lucerne flea</td>
<td>Sandy soils</td>
<td>Clay or clay-loam soils</td>
</tr>
<tr>
<td></td>
<td>Flea controlled in previous spring</td>
<td>High flea counts in flush pastures</td>
</tr>
<tr>
<td></td>
<td>Clean stubble paddock</td>
<td>previous spring</td>
</tr>
<tr>
<td>Cockchafer</td>
<td>Small larvae in 1st year of cycle</td>
<td>Large larvae in 2nd year of cycle</td>
</tr>
<tr>
<td></td>
<td>Grass free pasture year before crop</td>
<td>Grassily pasture</td>
</tr>
<tr>
<td></td>
<td>Grass free lupin or canola stubble</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cereal aphids</td>
<td>Long dry summer with little grass or volunteer</td>
<td>Summer rains</td>
</tr>
<tr>
<td></td>
<td>cereals</td>
<td>promoting grasses and volunteer cereals</td>
</tr>
<tr>
<td></td>
<td>Few perennial grasses in district</td>
<td>Green perennial grasses in district</td>
</tr>
<tr>
<td></td>
<td>Late planting</td>
<td>Early planting</td>
</tr>
<tr>
<td></td>
<td>Long cold winter</td>
<td>Long growing season</td>
</tr>
<tr>
<td></td>
<td>Low yield potential (below 3 t/ha)</td>
<td>Yield potential greater than 3 t/ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High soil nitrogen status</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Warm mild winters</td>
</tr>
<tr>
<td>Armyworm</td>
<td>Long dry summers</td>
<td>Wet summers with volunteer crop barley or</td>
</tr>
<tr>
<td></td>
<td>Few armyworm in previous spring</td>
<td>ryegrass</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Previous spring late with high armyworm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>numbers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Early break with mild winter</td>
</tr>
</tbody>
</table>

**Description**

The caterpillars are pale to deep brown with a tinge of green gut contents showing through. The head is black or dark brown. The caterpillars are found in web-lined tunnels in the soil near to lopped plants.

**Life cycle**

Webworm moths fly in April and are attracted to thin dry stems of barley grass, silver grass, bromes and ryegrass from the previous year, or to grasses germinating from early rains. Stubbles of wheat and barley are not attractive to the moths. Eggs hatch with autumn rains and the small caterpillars feed on germinating grasses or cereals. Feeding continues through winter. Spring and summer is spent in resting stages within the tunnels, until moths emerge in autumn. Large numbers of straw coloured moths fly on autumn nights, and hide in pasture residues by day.

**Control**

Control of grasses in the previous year, or planting into grass-free stubbles are the best options for avoiding webworm damage. Early planting helps avoid damage because caterpillars are small. Later plantings are more at risk because caterpillars are larger. Maintaining a grass free fallow for three weeks will starve webworm to death. Insecticides are necessary if 25 per cent of plants are chewed at or just after emergence. Do not delay spraying as repeated lopping can kill plants. Webworm and cutworm can be controlled with the same sprays. For current insecticide recommendations.
refer to Bulletin No. 4286, Chemical control of insect pests in field crops and pastures.

**Cutworm** *(Agrotis spp.)*

**Damage**

Plants are chewed through at ground level and uneaten portions lie scattered on the ground near the stump of the seedling. Large areas may be affected, with two to three large caterpillars per square metre capable of causing serious damage.

**Description**

The *pink cutworm* is grey-green with a pink tinge, while the *bogong cutworm* is dark grey to almost black. They grow to about 50 mm, are smooth, sleek and fat, and curl up when disturbed. By day they hide just below the soil surface, usually near to damaged plants. A *brown cutworm* with a herringbone pattern along its back is sometimes found in south coastal districts. It is often found on the surface during the day. Occasionally armyworm damage in autumn can look like cutworm attack (see armyworm).

**Life cycle**

Cutworm can have several generations each year, with moths active throughout the year, depending on the availability of food plants. They lay eggs on soil or plant material close to the ground. The adults are large stout bodied moths with colours and patterns varying between species. Numbers in autumn will depend on the supply of food plants over summer in response to summer rains.

**Control**

Paddocks managed to control grasses and weeds the previous spring, and summer weeds if there has been significant summer rain, will be at low risk for cutworm. Early planted crops are at less risk than those planted in June or July. Sprays are very effective, and should not be delayed if large areas are affected. The same chemicals are effective for cutworm and webworm. For current insecticide recommendations refer to Bulletin No.4286.

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**Desiantha weevil** *(Desiantha diversipes)*

**Damage**

Desiantha larvae are occasional pests of barley seedlings in south coast districts. In severe infestations, hundreds of hectares of crop may be killed. The larvae feed on germinating seeds, on roots and on the coleoptile. This results in non-emergence of seedlings, or wilting and death of seedlings with up to two tillers. Large larvae from early hatchings do most damage. Late planted crops are most at risk.

**Description**

The larvae are white, legless grubs to 6 mm, with orange-brown heads. They live in the soil and are difficult to find. The adults are grey-black weevils to 5 mm, and have a typical weevil snout.

![Desiantha larvae and a stunted barley seedling on which they were feeding](image)
CHAPTER SEVEN

INSECT PESTS OF BARLEY

Redlegged earth mite
(Halotydeus destructor)

Damage
Mites rupture surface cells of seedlings. Light damage shows as silvered patches, while bleached and shrivelled leaves result from severe infestations. Usually damage is confined to the first two to three leaves, and is seldom severe enough to cause yield losses. Plants growing slowly in cold waterlogged soils are most at risk.

Life cycle
Adults feed on summer weeds and plants germinating with summer and autumn rains, and then lay eggs in the soil. On hatching, larvae burrow down to feed on germinating seeds, roots and shoots. Feeding continues through winter into early spring, when they pupate to emerge as adults from late spring to summer. They can climb plants to the heads, and may be harvested with the grain. They do no damage, but are responsible for rejection of grain delivered to Cooperative Bulk Handling.

Control
Paddocks that were spray-grazed the previous spring to control grasses and weeds, and treated to control summer weeds will have a low risk of damage. Early planting and shallow seeding will also minimise losses. Shallow sands over gravel or clay are most likely to have desiantha weevil problems. Where the pest is confirmed, sowing insecticide-treated seed at 90 kg/ha is recommended. Insecticides sprayed after planting are not effective. For current insecticide recommendations refer to Bulletin No.4286.

Lucerne flea
(Sminthurus viridis)

Damage
Lucerne flea eat the top surface of leaves removing all the green tissue so only the back of the leaf remains. In severe cases, plants look bleached, and may die. Severe damage is not common.

Description
Adult lucerne flea are predominantly green-yellow insects up to 4 mm, fat and almost drop shaped. When disturbed they spring up to 300 mm away from the plant. If many fleas are present this movement catches the eye as a shower of pale green specks.

Life cycle
Lucerne flea are restricted to soils containing clay, which the female uses to encase her eggs. Heavy autumn rains soak through the cemented soil pellets, and cause the eggs to hatch. Several generations of lucerne flea develop while conditions are wet during winter and early spring. Eggs laid in late spring survive in their drought proof casings until the following autumn.

Control
As for redlegged earth mite. Grazing the previous spring is not as effective against lucerne flea as it is for redlegged earth mite. Paddocks with heavy soils being prepared for cropping in the following year should be treated in spring to control flea. For current insecticide recommendations refer to Bulletin No.4286.
Cockchafers
(Heteronyx obesus, and many other species)

**Damage**

Although it seldom happens, cockchafers can kill extensive areas of crop in some seasons and districts. The larvae live in the soil and feed on dead organic matter and plant roots. Of the many species found in Western Australia, only *Heteronyx obesus* damages crops. Damage occurs every second year, because this insect has a two-year life cycle.

**Description**

Cockchafer larvae have a brown head capsule and mouth parts, and three pairs of legs. They characteristically curl into a ‘C’ shape, and are creamy white, often with a bluish black colour of their gut contents showing through at the rear end. Sizes range from 2-25 mm long. The adults are stout bodied (5-20 mm) brown to black beetles that fly strongly. There are many species, difficult to identify, especially as larvae, so it is almost impossible to tell which are pests and which are not.

**Life cycle**

Depending on the species, life cycles take one or two years to complete. The only identified pest, *Heteronyx obesus*, has a two-year life cycle. In the first year, the larvae are small and do not cause damage to crops. In the second year they are larger and capable of damage. Larvae feed in autumn and winter. Adults emerge in early summer and feed on native plants, especially eucalypts. Eggs are laid in paddocks through summer into autumn.

**Control**

Control of cockchafer larvae is rarely warranted. Insecticides applied after planting do not kill the larvae underground. The small larvae in year one of their life cycle require grass roots to survive, so grass control either in pasture or a lupin rotation before the barley crop should minimise damage. Two years of grass control is preferable. Cultivation, early sowing, shallow sowing and sowing treated seed at high seeding rates may help. Large populations of non-pest species can exist without causing significant damage. For current insecticide recommendations refer to Bulletin No.4286.

Aphids
(Rhopalosiphum maidis, *R. padi*)

Cereal aphids have become a major pest of barley in medium to high rainfall areas. They have always been present, but did not cause significant yield reductions while crop yields remained well below yield potentials. As crop technology improved after about 1985 and yields increased from less than 2 t/ha to 4-5 t/ha, aphids became increasingly important.

Numerous trials have recorded yield losses of 0.5-2.0 t/ha in good crops with yields in the range of 5-7 t/ha. Achieving high yields has required good plant protection to capitalise on good agronomy - the 'high yield crop package'.

Trials have shown that aphids, barley yellow dwarf virus (BYDV) which is transmitted by aphids, and foliar diseases must be controlled to maximise yields. At yield potentials above 3.5 t/ha the crop is good enough to pay for aphid and disease control.

Cereal aphids congregated in the growing tip
In districts with yield potentials less than 3 t/ha (as determined by rainfall and growing season) the risk of losses due to aphids is less. However, if such districts strike a season with summer rain and a longer growing period, aphids may cause as much damage as in the medium to high rainfall areas.

It must be stressed that the value of aphid control depends on how well the crop has been set up (no root disease, paddock selection to avoid waterlogging, optimum time of planting for the variety, correct plant density, adequate fertiliser, foliar diseases controlled, no weeds).

**Damage**

Cereal aphid damage in barley has few obvious signs or symptoms, apart from the presence of aphids. If there are more than 50 aphids per tiller, the plants can become sticky with honey dew excreted by the aphids (see photograph). Lower leaves can become yellow and shrivelled, but this may also be due to age, shading, nitrogen loss, or disease. Aphids affect cereals by direct feeding on plants, and/or by transmitting BYDV. BYDV is introduced into the crop by aphids flying in from infected perennial grasses, annual grasses, or neighbouring crops.

The virus can be spread within the crop by wingless aphids moving from infected plants to neighbouring plants. Virus-affected plants may show symptoms of yellowing.

Direct damage occurs when colonies of 10-100 aphids develop on stems, leaves and heads, at any time from the two-leaf stage through to head filling. Losses are due to the combined effects of reduced tiller numbers, reduced grains per head, and lighter grain weight. The degree of damage depends on the percentage of tillers infested, aphids per tiller, and the duration of the infestation. Low populations (less than 20 per tiller) from tillering to flag emergence can cause as much yield loss as high numbers (more than 100 per tiller) after flag emergence.

**Description**

Corn aphid and wheat/oat aphid cause most yield loss. Wingless females are about 0.2-2.5 mm long. Rice root aphid and grain aphid are also found in cereals and may be important as virus vectors. Corn aphids are dark blue-green to grey-green, often with a fine white powdery dust over the body. Colonies develop within the furled tip of tillers, starting any time from seedling stage to head emergence. Few farmers see them because they are hidden in the furled leaves. Barley is most likely to be affected. Corn aphid probably kills tillers, resulting in fewer heads.

Wheat/oat aphids vary in colour, from mottled yellow-green through olive-green and dusky brown, to a blackish green. Colonies develop on the outside of tillers from the base upwards, on stems, nodes and backs of mature leaves, starting at any stage between two-leaf and grain filling. Heavy infestations can blacken stems and heads, and are the aphids most commonly reported by farmers. Wheat/oat aphids are more mobile than corn aphids, and can drop to the soil and crawl to other plants. They cause yield losses by reducing grain weight and grains per head. They also spread BYDV.

Rice root aphids are like wheat/oat aphids, but can also infest plant roots. They have a reddish patch in the middle of the back, and are most likely to be found in drier agricultural areas.

Grain aphids are dusky green with yellow-green tinges, usually found in spring, without developing large colonies.

Rose-grain aphids are potentially serious pests, but are yet to enter Western Australia from the eastern States where they are widespread. They are green spindle-shaped aphids attacking wheat and barley during grain filling.

**Life Cycle**

Winged cereal aphids fly into crops from pasture grasses, volunteer cereals or neighbouring cereal crops, and start colonies of wingless aphids. All the aphids are female and reproduce without mating. Reproduction is rapid when weather conditions are favourable, leading to population outbreaks. When plants become unsuitable or overcrowding occurs, winged aphids redevelop and migrate to other plants or crops. They can carry viruses in saliva.
BYDV damage is most serious when plant infection occurs early in the season.

**Control for feeding damage**

In southern areas, barley should be checked from late tillering onwards for corn aphids in the fulled growing tips, and for wheat/oat aphids on stems, backs of leaves and in the crown. Crops expected to yield 3 t/ha or more are most at risk. Spraying is worthwhile if 50 per cent of tillers have 10 to 15 or more aphids. Mixed infestations of both aphids may cause more damage than either species on their own.

Crops sprayed before Zadoks stage 30 may need re-spraying at Zadoks stage 50 or later, if aphid numbers build up again. Parasitic wasps, ladybirds, lacewings and hoverflies can provide useful biological control, mainly by preventing secondary outbreaks. The use of 'soft' insecticides that only kill aphids is advocated.

**Control for BYDV**

When spraying aphids to control BYDV it is necessary to spray at the first sign of aphids. In high BYDV risk areas, trials using an experimental insecticide as a seed dressing, or applying synthetic pyrethroid insecticides before and after tillering, reduced BYDV infection to about 5 per cent, compared with no treatment where BYDV infections of 80 to 100 per cent were recorded. In these experiments, aphid numbers were always less than 10 per tiller. Synthetic pyrethroids appear to prevent migratory winged aphids from feeding and therefore prevent BYDV transmission. For current insecticide recommendations refer to Bulletin No.4286.

**Armyworm**

*Mythimna convecta, M. loreyiinima, Persectania ewingii, P. dyscrica*

Armyworm are sporadic pests of barley. In outbreak years they can lop nearly 100 per cent of ripe heads within two days. The dense canopies of high yielding barley crops are likely to make it more difficult to kill all armyworm in a crop with insecticide. Experience has shown that the greatest losses can occur in the densest areas of crop.

Armyworm and typical damaged stem and lopped heads on ground

**Damage**

As crops ripen in late spring, large armyworm larvae climb up stems and chew through just below the head, causing it to fall to the ground. This is the most costly damage caused by armyworm. Often awns will be trimmed before head lopping occurs. The caterpillars are chasing the final green material on the plant. Armyworm can also cause heavy defoliation while the crop is still green. Occasionally armyworm infest seedling crops and cause damage similar to that of cutworm. They are much more difficult to kill than cutworm, so correct identification is necessary. Armyworm are most prevalent in south coast areas; occasionally inland areas as far north as Geraldton are affected. Caterpillars may be hard to find. Rolls of plants can be knocked together, and the space between them inspected for larvae. Their droppings, which look like small green hay bales, are obvious on the ground.

**Description**

Four species of armyworm exist in Western Australia -
- common armyworm,
- sugarcane armyworm,
- southern armyworm,
- inland armyworm.

Their larvae are similar and cannot be reliably separated. Caterpillars are smooth and sleek, have few bristles and are
about 40 mm long. They have large heads and a collar with three white stripes. This distinguishes them from cutworm and native budworm. Colours vary from pale straw to almost black. This colour range is a guide to numbers in a crop, with pale dominant at low numbers and very dark dominant in high populations. The adult moths have wing markings characteristic for each species.

Life cycle

Moths lay eggs into grasses (especially ryegrass) or cereals. Larvae hatch and feed to full size before burrowing into soil or under stumps or rocks where they pupate. Moths emerge from the pupae, mate and lay eggs again. There does not appear to be a resting stage. Populations are regulated by food supply. If summer rains maintain a supply of green grasses or volunteer cereals, armyworm numbers can increase rapidly.

Large numbers of moths following a wet summer set the stage for population increases over winter and spring, resulting in pest outbreaks in late spring. There may be four generations per year. Common and sugarcane armyworm tend to remain within a district. Inland armyworm can breed up in pastoral areas in wet summers, giving rise to flights of moths that invade adjacent agricultural areas.

Control

If seasonal factors indicate a high risk year, crops should be monitored from mid spring onwards. Maximum damage will occur if head ripening is synchronised with larvae achieving full size. Three large caterpillars per square metre can cause economic damage. If larvae mature while the crop is still green, leaves are stripped and some heads are lopped. If the majority of larvae are small when the crop ripens, and hot weather sets in, the caterpillars die without doing damage.

Small larvae tend to feed on leaves and immature tillers at the base of the plant. In dense crops with a high yield potential, large caterpillars will move to the top of the crop, while smaller ones stay near the base of plants. Insecticides have difficulty penetrating to the base of the crop. Repeated sprays at high rates may be required. Synthetic pyrethroids are variable in their effectiveness. Organophosphates such as trichlorfon may be too short lived to be effective in dense crops. In some situations it may be feasible to windrow the crop before serious damage has occurred. For current insecticide recommendations refer to Bulletin No. 4286.

Further information

Bulletin No. 4185 Insect and allied pests of extensive farming

Bulletin No. 4286 Chemical control of insect pests in field crops and pastures
8. LEAF DISEASES OF BARLEY

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Scald

Scald, is one of the most widespread leaf diseases of barley in Western Australia and is caused by the fungus Rhynchosporium secalis. This is a serious disease that can reduce yield by as much as 40 per cent and cause discolouration of the grain. It is found in all parts of the cereal growing areas of the State but the most severe outbreaks occur in medium/high rainfall areas.

Symptoms

Lower leaves are usually affected first. The first sign of the disease is a blue/grey, water-soaked area on the leaf (see photo). These lesions become bleached with a distinctive brown margin. Lesions are most commonly seen on the leaf blades but at high levels of infection are also seen on the leaf sheath and head.

Source of infection and spread

The most common source of primary infection is from the residues of a previously infected crop or barley grass. Spore release and spread from stubble occurs with rain. Spores splash on and infect emerged barley plants and form the primary infection in the crop. Scald can also be spread on seed from an infected crop and this can be an important source of infection in rotation crops.

Rainsplash also spreads spores within the crop canopy. Scald is often seen as ‘hot spots’ within the crop indicating that the initial infection has taken place in the centre of the worst affected area or ‘hot spot’ and then spread to neighbouring plants by splash.

Conditions favouring disease

- Temperature and moisture - The optimum temperature for both spore production and infection is 15 to 20°C. Rain aids the spread of disease and the most rapid increase in disease is observed early in spring when temperature and moisture conditions are ideal.

- Sowing date - Early sown crops develop higher levels of scald. Early sown crops may be exposed to the heaviest release of spores from infected residues and develop upper canopy leaves at times in the season favourable to disease spread.

- Nutrition - Disease is more severe at higher levels of nitrogen supply.
Management and control

- Varietal resistance - There is a large range of levels of varietal resistance among commercially grown varieties. When sowing early, use a resistant variety wherever possible. Varietal resistance may eventually break down. The fungus is highly variable and is eventually able to attack previously resistant varieties of barley. Observations in Western Australia suggest that this process takes a number of years and the resistant variety Skiff has remained resistant in Western Australia since release in 1988 while there have been reports of breakdown in South Australia. See the Crop variety sowing guide for Western Australia for the current status of varietal resistance.

- Rotation - Avoid sowing into a barley stubble as this gives by far the most severe outbreaks.

- Seed dressings - Baytan® (100 to 150 g/100 kg seed) and Armour® (100 g/100 kg seed) applied to the seed can control scald for up to eight weeks. Treatment is essential in multiple cropped susceptible varieties and is recommended where seed is retained from a susceptible infected crop.

- Fungicide sprays - Bayleton® at 1 L/ha and Benlate® at 500 g/ha are registered for control of scald but are not generally used because of cost. Folicur® at 250 mL/ha is currently being registered and when available will make fungicide sprays more feasible. Fungicide is applied to young infected crops at tillering and during early stem extension (Zadoks 31 to 33).

Net blotch

Net blotch is one of the most widespread leaf diseases of barley in Western Australia and is caused by the fungus Drechslera teres. Two types of the fungus occur in WA, net-type and spot type which have different symptoms and distributions.

Net-type net blotch is more common in central and southern agricultural regions. On susceptible varieties small brown blotches elongate and form thin brown streaks along and across the leaf blade. This sometimes forms a net like pattern often surrounded by yellowing (see photo). Lesions can be restricted on less susceptible varieties.

Spot type net blotch is limited to northern agricultural regions. Symptoms are dark brown eliptical spots surrounded by yellowing.

Source of infection and spread

The most common source of primary infection is residues of a previously infected crop or barley grass. The disease is spread by wind. Conidia (spores), from stubble land on and infect emerged barley plants and form the primary infection in the crop. Within the crop canopy, conidia are spread as the secondary infection by wind. Net blotch can also be spread on seed from an infected crop although this is
thought to be a less important source of infection than crop residues.

**Conditions favouring disease**

- Temperature and moisture - The optimum temperature for spore production and infection is 15-25°C. Release of spores occurs at near 100 per cent relative humidity and when humid, moist conditions persist for 10 to 30 hours or longer, infection of barley leaves is greatest.

- Sowing date - Early sowings increase the level of disease. In southern areas, April sown barley is particularly prone to net blotch.

**Management and control**

- Varietal resistance - There is a large range of varietal resistance to both types of net blotch among commercially grown varieties. When sowing early, use a resistant variety wherever possible. Varietal resistance may eventually break down. Changes in the fungus population occur such that it is eventually able to attack previously resistant varieties of barley. Observations in Western Australia suggest that this process takes a number of years. See the [Crop variety sowing guide for Western Australia](#) for the current status of varietal resistance.

- Rotation - Avoid sowing into a barley stubble as this gives by far the most severe outbreaks.

- Seed dressings and fungicidal sprays are ineffective for net blotch.

**Symptoms**

The first signs of the disease are white powdery spores on the leaf blades (see photo). The area surrounding the spores turns yellow as the fungus depletes the leaf of nutrients. Older infections turn grey and may develop small black fruiting bodies called cleistothecia. When spores are washed off by heavy rain, old infections remain as brown patches on the leaves.

**Powdery mildew**

Powdery mildew is most common in the coastal areas of the Western Australian cereal belt and is caused by the fungus *Erysiphe graminis*. With the widespread use of seed dressings in recent years the disease is not seen as often or at the high level of severity that typified the 1960s to mid 1980s. At high levels of infection, powdery mildew is a serious disease that can reduce yield by as much as 25 per cent and cause loss of grain weight.
**Source of infection and spread**

The most common source of primary infection is wind blown ascospores from the cleistothecia of infected crop residues. Spores land on and infect emerged barley plants and form the primary infection in the crop which appears as the white powdery spores known as conidia.

Within the crop canopy, the white fluffy conidia are spread as the secondary infection by wind. In favourable conditions the cycle of germination of spores, infection and subsequent spore production can be completed in as little as seven days. This causes the characteristically rapid build-up of disease in the crop. Powdery mildew infections in crops do not tend to appear in 'hot spots' but are more general owing to the disease being spread by wind.

**Conditions favouring disease**

- Temperature and moisture - The optimum temperature for both spore production and infection is 15 to 22°C and is retarded at temperatures above 25°C. Mildew often disappears rapidly in the higher temperatures and low relative humidity of the spring months. Mildew is not spread by rain and free water is considered to be lethal to powdery mildew spores.

- Nutrition - Disease is much more severe at higher levels of nitrogen supply and variations within a paddock are often related to nitrogen nutrition. Low potassium levels favour disease development, especially if combined with high nitrogen levels.

- Sowing date - Later sown crops (June) have tended to be more at risk than early sowings.

- Plant development stage - Early infection in the crop, in the stage leading up to stem elongation, has the greatest effect on yield as it reduces tillering.

**Management and control**

- Varietal resistance - Varietal resistance is available among commercially grown varieties. Changes in the pathogen population occur such that it is eventually able to attack previously resistant varieties of barley. In the past varietal resistance has not been durable and under pressure from the high levels of disease was known to break down within several years. With disease now at generally lower levels due to the use of seed dressings, varietal resistance may be more persistent than has been seen in the past. See the Crop variety sowing guide for Western Australia for the current status of varietal resistance.

- Seed dressings - Baytan® (100 to 150 g/100 kg seed) and Armour® (100 g/100 kg seed) applied to the seed can control powdery mildew for up to eight weeks. Because of the importance of early infection in causing yield loss further control is rarely necessary.

- Fungicide sprays - Bayleton® at 1 L/ha is registered for control of powdery mildew but is
expensive and would only be warranted in very high yielding crops where seed dressing was not used to control the early stages of the disease. The optimum time of application of fungicide for maximum yield response is during early extension (Zadoks 31 to 33) and when no more than 5 per cent of the top three leaves are affected by the disease. If the infection level is higher (and it usually is by the time it is noticed in the crop) spraying will not control powdery mildew.

Barley yellow dwarf virus

Barley yellow dwarf virus (BYDV) is transmitted by cereal aphids and can be damaging in the high and very high rainfall areas of the south-west and south coast regions.

Symptoms

The disease generally appears in well defined patches that are the centre of aphid activity. Severely affected plants may be stunted with bright yellow leaf tips and pale stripes between the leaf veins. When the head emerges, awns are twisted and the head may be sterile. General crop infection may follow this stage if aphids have not been controlled. More often plants have a low level of infection and show very few symptoms although 10-20 per cent yield losses can still occur.

Source of infection and spread

The disease is spread by the cereal aphids *Rhopalosiphum maidis* (corn aphid) and *Rhopalosiphum padi* (wheat/oat aphid) after over-summering on perennial grasses and volunteer cereals that germinate on summer rains. Because the disease is transmitted by cereal aphids the severity of disease is very dependent on seasonal conditions and the build-up and spread of aphids.

Conditions favouring disease

- Summer rain - Summer and early autumn rain which results in volunteer cereals and growth of perennial pastures will lead to a build-up in aphid numbers.
- Sowing date - Early sowings increase the level of disease. In the southern areas, April sown barley is particularly susceptible. This may be a result of the early rains that allow the crop to be sown early but are also favourable for the build-up of aphids. Research has shown that delaying sowing to June can markedly reduce the level of BYDV infection. In general it is not recommended to delay sowing to reduce BYDV as yield penalties from late sowing are likely to outweigh the benefit of reduced disease level.

Management and control

- Varietal resistance - When sowing early, use a tolerant variety if appropriate. BYDV consists of a number of closely related virus strains and resistance may be ineffective if certain strains predominate.
- Aphicide sprays are useful in high risk areas. Aphids need to be sprayed at the first sighting to prevent spread of BYDV. For more detailed information see the chapter on 'Insect pests'.
Other leaf diseases

- Barley stripe (Pyrenophora graminea) - this seed-borne fungal disease is comparatively rare but can limit yield if allowed to build up. Leaves of infected plants show long brown stripes which continue down the leaf sheath. Drying leaves split along the stripes. Infected plants usually fail to produce seed but infect seed on other plants. Infected seed appears normal. Use clean seed from uninfected crops. No seed treatments are registered for barley stripe control though some are moderately effective.

- Halo spot (Pseudoseptoria stomaticola) - this splash-borne fungal disease rarely becomes severe enough to limit yield. Lesions can be similar to scald but are much smaller. Cool moist conditions favour the disease. No control is warranted.

- Leaf spot (Dreschlera campanulata formerly D. verticillata) - this common minor leaf spot causes small tan lesions ringed by a black margin. It is not known to affect yield. It has a wide host range on grasses and cereals and survives on infected residue.

- Arno Bay blotch (Dreschlera hordei) - is a rare leaf spot generally not found in Western Australia. It causes oval dark brown spots which tend to become straight sided as they enlarge. The disease is borne on infected barley stubble. The disease is not known to reduce yield in Western Australia but may be a potentially damaging disease.
• Wirrega blotch (*Dreschlera wirreganensis*) - is a relatively common leaf spot causing large brown lens shaped blotches with chlorotic margins extending lengthwise along the leaf. Lesion centres may become holed. This pathogen has a wide host range on grasses and cereals and survives on infected residues. Control of this disease has not been warranted.

• Physiological leaf spot (non-pathogenic) - is a common phenomenon in barley. Such leaf spotting, which may take various forms, can not be attributed to a pathogen. Environmental stresses such as nutrient disorders can cause physiological leaf spotting and some cultivars may be more prone than others.

**SMUTS OF BARLEY**

**Loose smut**

Loose smut, caused by the fungus *Ustilago tritici* is widespread in the medium to high rainfall areas of Western Australia. This is a potentially serious disease if not kept under control by the use of seed dressings.

**Symptoms**

The first sign of the disease is when the infected heads emerge as a mass of dark brown powdery spores. These are blown off in the wind leaving inconspicuous bare stalks which may be the only sign of the disease late in the season.
Source of infection and spread

Infection is seed-borne. In infected plants, smutted ears emerge earlier than normal ears of healthy plants. The thin membrane holding the mass of spores inside rupture at about the time that healthy heads emerge. Spores are spread by wind and the fungus grows inside the developing seed. The seed shows no sign of infection until the following crop produces infected heads.

Conditions favouring disease

- Climatic conditions - The optimum temperature for spread of spores and infection is from 16 to 22°C, especially when combined with moist conditions during flowering.

Management and control

- Fungicide seed dressings with systemic activity are necessary to kill infection within the seed. Seed dressings may not be fully effective, particularly if the seed has come from a crop with a heavy disease load.
- Seed source - if a crop has more than 5 per cent of heads infected with loose smut do not retain for seed.

Covered smut

Covered smut, caused by the fungus Ustilago segetum var. hordei is easily controlled by the use of seed dressings and therefore is rarely seen in Western Australia.

Symptoms

The first sign of the disease is when dark compacted heads emerge and remain conspicuous and intact until harvest. In these infected heads, smut balls take the place of the grain. Fragments of infected heads in harvested grain are a tell-tale sign of the disease.

Source of infection and spread

The smutted balls are broken and crushed during threshing, releasing spores which collect on the outside surface of barley seeds. After seeding, the spores germinate at the same time as the seed and infect the seedling through the coleoptile.

Conditions favouring disease

- Climatic conditions - The optimum temperature for infection is from 20 to 24°C.

Management and control

- Fungicide seed dressings effectively control covered smut.
9. ROOT DISEASES OF BARLEY

Gordon MacNish

Esperance Agricultural Centre

The main root diseases of barley are take-all and rhizoctonia bare patch. There are a number of other root and crown diseases, but these are of limited importance to barley in Western Australia. These diseases include fusarium crown rot (caused by the fungus *Fusarium graminearum*), common root rot (*Cochliobus sativus*), pythium root rot (*Pythium* spp.) and cereal cyst nematode (*Heterodera avenae*). Only the two most important diseases are discussed in this book.

Take-all

Take-all is the most serious root disease of barley in Western Australia and is caused by the fungus *Gaeumannomyces graminis* var. *tritici*.

Distribution

Take-all disease occurs throughout the cereal belt (Figure 22), but is most common in the high and medium rainfall areas (400 to 750 mm annual average rainfall). It can be a very serious disease in the south coastal region.

Symptoms

Affected plants tend to occur in patches that vary in size from a few plants up to several metres across. Infection causes stunting, depending on severity. At heading, dead plants are conspicuous in an otherwise green crop. In the paddock, take-all is much more obvious on wheat than barley.

Infected barley plants have dark brown to black streaks or spots on the base of the stem. Roots of affected plants are dark brown to black due to fungal invasion. As the plant matures, the roots become rotten and brittle and the plant can be easily pulled from the soil.

![Figure 22. Distribution of take-all risk](image)

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THE BARLEY BOOK
Principles underlying the life cycle of the take-all fungus

Principle 1: The take-all fungus can only attack cereals and grasses.
Control implication: Non-grass hosts are excellent cleaning crops.

Principle 2: The take-all fungus must have a grass host to survive.
Control implication: Removal of grass hosts between cereal crops will significantly reduce carry-over.

Principle 3: The take-all fungus can survive in dead host tissue for one year and in ideal conditions for two years.
Control implication: Removal of hosts and rapid rotting of host tissue will speed up the death of the fungus.

Principle 4: Fast breakdown of infected tissue will shorten survival time.
Control implication: The longer the trash is in moist soil, the quicker the breakdown.

Hosts

The take-all fungus causes root rot on wheat and barley and, to a lesser extent, oats. Barley is much more tolerant to attack by the take-all fungus than wheat. The fungus also infects most volunteer and pasture grasses. Barley grass (Hordeum leporinum) is the most susceptible common grass, followed by annual ryegrass (Lolium rigidum) and silver grass (Vulpia sp.) while brome grass (Bromus diandrus) is least susceptible. The susceptibility of other pasture grasses falls within the range of these common pasture grasses.

The fungus does not infect non-grass pasture plants such as subterranean clover, medic or capeweed, or non-cereal crops such as lupins, peas or canola.

Carry-over

The take-all fungus survives over summer in the roots and crowns of plants infected during the previous growing season.

Survival is affected by soil conditions and tends to be longer where soil fertility has been improved by the establishment of pasture legumes. Its survival is also affected by soil moisture and temperature. In the absence of live host plants, the fungus persists longer in dry soils than moist, and longer with cool temperatures than with high temperatures.

At the break of the next growing season, the surviving fungus infects susceptible host plants when their roots grow near stubble or grass fragments that harbour the fungus. If no susceptible host root grows nearby, the fungus will remain in the fragments until they are broken down by the normal processes of decay.
Some pieces of debris may be large enough to remain relatively intact for one or two growing seasons, while most smaller pieces will break down in the first growing season. The amounts of viable fungus available to infect a following crop will therefore be greatly reduced by one season in which no host plants are available for the fungus to infect and on which to carry-over.

**Strategies for controlling take-all**

**Controlling take-all in a pasture: cereal rotation**

To grow a cereal crop that is virtually free of take-all, host plants need to be eliminated from the previous legume pasture.

The severity of take-all over the whole crop increases by about 5 per cent for each 100 kg/ha of grass dry matter in the previous year’s pasture (measured in spring). This is illustrated in Figure 23.

There are two options for manipulation of pasture (grass-legume mixtures) with herbicides to control take-all:

- seed set control two years before cropping; and
- selective grass control by spraying in the year before cropping.

Their effects are summarised in Figure 24. Both techniques aim to produce a pasture free of grass for most of the year before sowing a cereal crop. Both options have advantages and disadvantages.

**Seed set control**

Either a broad spectrum or a grass-selective herbicide can be used when most grass in the pasture is in the early stages of flowering. This ensures that the minimum amount of viable seed is set for germination in the following year. This technique can be used only if the paddock to be cropped is known two years in advance.

All pasture grasses must be flowering at about the same time so that a single spray will minimise the amount of grass seed set. The herbicide needs to be applied early enough to prevent viable seeds being set, but late enough to prevent the production of new tillers that would set more seeds.

Also, the legume component of the pasture must set enough seed to be competitive with grasses that germinate in the following year; that is, the year of pasture before cropping.

**Selective grass control**

A broad spectrum or selective herbicide can be applied at about the six-leaf stage of the clover or medic plants in a pasture during the year before a cereal crop is sown.

After grass control, pasture production is reduced in late autumn and early winter when grazing is already in short supply. However, to complete the control of grass, grazing pressure must be maintained on the pasture to prevent tillers developing on sprayed plants and the establishment of grasses that germinate late.

Before using this method of pasture manipulation, first ensure there are 1000 to 2000 plants per square metre of clover or medic in the pasture. This number of clover or medic plants is required to compensate for the loss of grass in the pasture and to smother grass plants that survive or emerge after spraying.

Herbicide must be applied as early as possible in the growing season to allow the longest possible time for the breakdown of grass root fragments harbouring the fungus. Delaying herbicide application by as little as three weeks can lead to a considerable increase in the amount of take-all fungus that survives to the end of the growing season.
A strategy for very grassy pastures

In a predominantly grass pasture where the numbers of subterranean clover or medic plants are too low to use selective grass control successfully, there are two choices:

- Combine the two options for grass control. Seed set control with a grass-selective herbicide two years before cropping will allow the legume to set more seed and reduce the grass seed-bank. It should be followed by a selective spray to further decrease grass in the year before a cereal crop.
- Use a rotation with a non-host crop before sowing to barley. However, grasses must still be completely controlled within this crop to provide a break in the disease cycle.

Other advantages gained by eliminating grasses from pastures

As well as controlling take-all, there will be:
- fewer grass weeds in crops;
- the opportunity to sow earlier than usual;
- increased nitrogen fixation by pastures;
- better quality grazing for stock;
- minimal grass seed contamination of wool; and
- control of annual ryegrass toxicity.

Barley or wheat?

Because barley is more tolerant to take-all than wheat, there are some situations where the potential risk from take-all would make it wise to change from wheat to barley. Such a situation would be where the grass control program had failed to give complete elimination of grass. Another situation would be
where two cereals had to be sown consecutively. Wheat following wheat is likely to give a very high take-all risk. If a non-host cleaning crop like lupin, peas or canola cannot be used then barley is a far better option than wheat.

Results from a large number of experiments have shown that there is a good correlation between increase in take-all severity and increases in barley yield compared with wheat yield (Figure 25). There is a 1 per cent increase in barley yield compared with the wheat grown under the same conditions. Thus if the level of severe take-all on the wheat was 25 per cent, then the yield in the barley compared to the wheat would be 125 per cent compared with 100 per cent.

\[\text{Yield of barley relative to wheat} = 0 \text{ to } 225\]

<table>
<thead>
<tr>
<th>Take-all severity on roots of wheat</th>
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**Figure 25. Relative yield of barley to wheat and the severity of take-all**

Because of the price differential between wheat and feed barley, a 25 per cent higher yield is required from barley to give an equal return. A 25 per cent increase is equivalent to a take-all severity of 25 per cent in wheat grown at the same site. From Figure 23 it can be seen that 25 per cent severity could be expected if there was approximately 700 kg/ha grass dry matter in the previous season pasture. Depending on conditions (e.g. dry season compared with a wet season) the amount of grass could range from 1100 kg/ha to 500 kg/ha to give a 25 per cent take-all severity. A range of grass levels in pasture and lupins is shown in the following photographs.

**Symptoms**

The most obvious symptom of rhizoctonia bare patch is the distinct edge to the patch. There is an abrupt change from diseased plants to apparently healthy plants a few centimetres away.

**Rhizoctonia bare patch**

Rhizoctonia bare patch is caused by the fungus *Rhizoctonia solani* AG-8 that survives indefinitely in the soil. It can attack cereals, crop legumes, pastures and weeds and has become widespread in the cereal belt (Figure 26).
Plants within the patch are stunted, with stiff, rolled leaves and are sometimes darker green. Their roots are short with brown spear-tipped ends. Plants may remain stunted until maturity or may die prematurely allowing the area to become overgrown with weeds. Towards the end of the growing season the edge of the patch usually becomes less distinct.

**Control**

- The order of susceptibility of cereals to rhizoctonia bare patch is barley (most susceptible), wheat, oats (least susceptible). The relative position of triticale and cereal rye is not known.
- Use a modified combine with tines that cultivate to 10 cm but place the seed shallow (2 to 5 cm) or avoid direct-drilling in paddocks prone to rhizoctonia bare patch. Scarify to 10 cm.
- Deep ripping reduces the incidence of disease.
- Apply nitrogen at 15 to 25 kg/ha. All sources of nitrogen are equally effective.
- As all crops and pastures are susceptible, rotations have little or no effect on the incidence of rhizoctonia bare patch.

**How to look for the disease**

The disease will be evident as distinct patches throughout the life of the crop. Roots of affected plants are poorly developed with spear tips evident after washing to remove soil.
10. HARVESTING TECHNIQUES AND GRAIN QUALITY

Kevin Young
Esperance Agricultural Centre

"The first point to be considered is when barley should be cut. Upon this opinions differ: my experience is that barley should be ripe, but not overripe, that is, the grain should have attained its full size, which will take place just before it is hard, while there is sufficient sap in the straw to prevent shedding. Nothing is gained by cutting barley dead ripe, on the contrary, the quality is impaired for malting purposes, and fully one-fourth of the best grain will be left in the paddock."

Extract from Growing barley for malting purposes - hints to our farmers by Chas. Redwood, Maltster. Journal of the Department of Agriculture, Western Australia, April 1900, Vol 1.

Acknowledgement
Much of this chapter is a summary of trials conducted by Mike Bolland and Richard Snowball.

Harvest yield and quality
The harvesting operation is a critical process in determining both grain yield and quality. For example, grain that is over-threshed causing cracking and skinning will have poor viability and cause low malt extract as well as an increased risk of microbial infection when malted. The method of harvest will have a large bearing on grain moisture content, likely yield losses and risk of staining.

There are three main options available when harvesting a barley crop:

- direct heading of 'dry' grain;
- direct heading and 'grain drying';
- swathing.

Direct heading of 'dry' grain
The simplest and, at present, most common harvesting method is to wait until the grain has ripened and dried to a moisture content of less than 12 per cent so that it can be delivered directly to the receival point. While this is the cheapest method of harvesting, the danger is that there may be long periods of high relative humidity in which harvesting of 'dry' grain is not possible, causing considerable delays. During this time losses due to shattering (or neck-break) can be considerable. For a variety that is very susceptible to shattering, such as the malting variety Clipper, losses can be as much as 0.5 to 0.75 per cent of the total yield for each day's delay in harvesting a ripe crop (Figure 27).

The variety Dampier has been measured to lose between 0.25 and 0.4 per cent per day under the same conditions, and Stirling has been assessed as very similar to Dampier. Varieties such as Franklin and Skiff have much reduced susceptibility to shattering, however, under the extreme conditions experienced during the 1993 harvest on the south coast even these varieties suffered large losses. Any delays also increase the likelihood that the grain will be discoloured by early summer rains or there will be hail damage.

Figure 27. The effect of harvest delay on yield loss in barley
Direct heading and 'grain drying'

To avoid harvesting delays the grain can be direct harvested above 12 per cent moisture and then put through a grain dryer. When drying grain that is to be used for malting it is important not to affect grain viability. For this reason grain that is to be dried should be harvested at no more than 20 per cent moisture and the drying temperature should not exceed 43°C. The same applies for barley that is to be used for seed. Barley that is to be used for seed must be brought down to less than 14 per cent moisture to avoid spoilage during storage. For feed barley the operation is not so critical as seed viability is not an important issue.

Swathing

Swathing (also referred to as windrowing) involves cutting the crop when the grain has reached the dough stage and is approximately 35 per cent moisture content. The crop is then allowed to dry in the swaths until the moisture content is below 12 per cent when it is harvested using a special pick-up front attachment.
Swathing of barley has many advantages

- Swathed barley matures more rapidly and is ready to harvest 5 to 15 days sooner than if left standing (Figure 28). This effectively reduces the period that the crop is exposed to potentially damaging rains - so the strategy for swathed barley should always be to get the maximum advantage by picking the crop up as soon as possible.

- Yield-loss from shattering is avoided while the crop is sitting in the swaths.

- Swathed barley is drier than grain in a standing crop so harvest can start earlier in the day and continue later than in a standing crop. Differences of one to two percentage units have been recorded so that extra time allowed in harvesting can be substantial. Once again this means that the crop will spend less time exposed to potentially damaging rains or hail.

**When to swathe**

Swathing can begin when grain moisture content is 35 per cent. This is at the dough stage (Z85) and there is very little green colouration left in the plant. Grain filling studies have shown that maximum grain weight is attained when all green tissue has gone from the flag leaf sheath and the peduncle (stem immediately below the head). Suggestions that swathing will eliminate the need to spray for armyworm control (see Chapter 7, 'Insect pests') are unlikely to be correct unless the armyworm outbreak occurs very late in the season. It is also highly unlikely that any movement of assimilates into the grain occurs after the crop has been cut and is sitting in the swaths.

**The swathing operation**

High yielding crops are likely to gain more from swathing than low yielding crops. Generally crops that are likely to yield less than 1.2 t/ha should not be swathed. Swather size or width of cut should be matched to header capacity. A double-up attachment on the back of the swather puts two swaths side by side and naturally requires a larger capacity header.

When the swath is picked up, the reel should be rotating slightly faster than ground speed, but not so fast that heads are knocked off the stems. The conveyor canvas should be revolving sufficiently fast so that it does not clog with crop material. The crop should be cut 10 to 20 cm above the ground. If the crop is too thin or the stubble too short to support the swath above the ground, the crop should not be swathed. Heads on the ground may sprout and attempts to pick up heads that are lying close to the soil.
surface will pick up soil. 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 heavily stained. Harvesting of the swathed crop must be completed as soon as possible.

**Staining**

Weather staining in barley is a common problem worldwide and especially so on the south coast of Western Australia where it is associated with the late spring/early summer rains. Staining takes two forms. One form is the yellowing or 'caramelling' caused by light showers which discoulours the grain without, it seems, the involvement of fungi. The second, more severe form, appears after heavier rains and is the grey discoulouration and black point that is associated with a number of fungi. This will be referred to as 'fungal staining' to distinguish it from caramelling.

There are a number of field fungi found on stained barley grains. The principal species include *Alternaria*, *Cladosporium*, and *Stemphylium*. Among the commercial Australian varieties there is no real difference in susceptibility to fungal staining. Differences that are reported are generally due to later maturing varieties which avoid the most damaging rains. There have been some reports from overseas of resistance to the fungi associated with fungal staining, but these varieties have yet to be tested under local conditions.
Among Australian varieties there appears to be subtle differences in degree of caramelling. Once again there have been overseas reports of differences in susceptibility to caramelling and, in future, overseas lines will be assessed alongside local varieties such as Stirling which appears to be particularly prone to caramelling.

The main concern with grain that has been discoloured by caramelling is that the darker colour is carried through to the malt and eventually, the beer. This is of particular concern when the brewer is producing a pale ale or light coloured lager.

Fungal growth on severely weather-stained barley creates much greater problems. Firstly, in the malthouse, stained barley can have low germinability (or ‘water-sensitivity’), indicating a higher level of dormancy. This means that the maltsters will most likely use stained grain as a last resort, storing the grain longer to overcome possible dormancy problems. In the brewery, problems can include poor lautering, reduced brewhouse yield, and in extreme cases, fermentation, flavour and stability problems. ‘Gushing’ or overfoaming, caused by a sudden release of carbon dioxide when packaged beer is opened, is directly related to microbial activity on weather-stained barley.

Strategies to reduce staining

At this stage the only strategy available to reduce staining is to try to avoid as much damaging rain as possible during flowering and grain filling by sowing malting barley no earlier than the optimum time. Also use swathing as a means of maturing the crop earlier and getting it in the bin as quickly as possible to reduce the time exposed to the weather. Obviously neither strategy will work every year, but a combination of both will mean that at least you have reduced the risk as much as you can.
Brewing is still the major end use of malted barley, with a small percentage of the malt being used for food products such as snack foods, malted drinks, multi-grain breads and breakfast cereals. You can alter the quality of the grain produced before it reaches the maltster.

Processing of malting barley grain

To be used for brewing, barley grain has to be malted. A simplified picture of the steps barley grain undergoes from malting in the malthouse up to mashing in the brewery is detailed in Figure 29.
To start malt production, the moisture content of the grain is increased from 10 per cent to between 42 and 48 per cent in a process called steeping. This stimulates germination. Germination, producing roots and shoots, occurs in a humidified atmosphere. The endosperm, which is the energy source of the grain during early growth, also changes in structure. This breakdown of the endosperm is called modification. The endosperm contains starch bound within a protein matrix.

Germination stimulates the release of diastatic enzymes from cells surrounding the endosperm. These diastatic enzymes are responsible for converting starch into fermentable sugars such as glucose and maltose. They cannot start modifying starch until barriers restricting their access to the starch are broken down. These barriers are the endosperm cell walls and the protein matrix. Only 5 to 10 per cent of the starch is degraded into fermentable sugars during malting. The breakdown of the protein matrix surrounding the starch granules releases simple proteins.

When the shoot is about three-quarters the length of the grain (or after four to six days), germination is halted by kilning. Kilning dries the grain, and promotes the development of colour and flavour. Root and shoot material impart an unpleasant, bitter flavour so they are removed after kilning. The malted grain is then stored at low moisture.

At the brewery the malted grain is milled. Milling breaks up the endosperm but leaves the husk intact so that it can be used as an aid during filtration.

The milled grain is then mixed with hot water in a process called mashing. It is during this mashing process that most of the starch is broken down into fermentable sugars. Malt extract is produced by filtering the liquid through the husks. The extract can then be used for making beer.

During fermentation, yeast converts the fermentable sugars
into alcohol. Soluble proteins in the extract are used by the yeast as a food source, impart colour to the wort and help stabilise the foam of the beer. The soluble proteins also contribute to the development of beer hazes.

By manipulating the conditions during malting and kilning the basic properties of the malt can be altered to suit the beer being produced. For example, the grain is kilned to a higher temperature for stout production. Genotype and environment, however, have a larger effect on the end quality of the malt produced. The maltster only fine tunes overall quality.

Any of the barley varieties we currently grow can be malted. Feed barley is not used for malting because the quality of the malt produced is inferior to Stirling.

What defines quality?

There are two components of quality in malting barley. The first is grain quality and the second is malt quality. Each of these quality parameters affect the efficiency at which the maltster and the brewer can produce malt and beer. The grain quality parameters are:

- protein,
- screenings,
- staining.

The malting quality parameters are:

- extract,
- diastase,
- viscosity.

The nature of each of these quality parameters is described below.

Grain quality parameters

Protein

The percentage protein in the grain is indicated by the total nitrogen concentration by weight of the grain multiplied by 6.25. Protein in malting barley is presented as a percentage on a dry basis (unlike wheat which is presented at 11 per cent moisture). Too much or too little protein is detrimental to the malting and brewing process.

High protein in barley affects production schedules of the maltster by increasing steeping times, affecting germination and
reducing modification. High protein is also associated with reduced starch deposition.

In the brewery, high protein in barley contributes to increased haze formation and can reduce the potential shelf life of beer (period of peak freshness and taste).

Low protein in barley, on the other hand, inhibits fermentation through a lack of substrate for the yeast and can reduce the stability of beer foam.

**Screenings**

Screening level is a measure of grain plumpness, with grain size being influenced by the amount of starch in the endosperm. The current export standard for determining grain plumpness is a 2.5 mm slotted sieve. Grain remaining on a 2.2 mm screen is used for malting. Grain plumpness is presented as either the proportion remaining on a screen or the proportion that passes through a screen as a percentage.

A low variation in grain size improves the processing of barley in the malthouse. High screenings affect the rate of grain modification, because small grains germinate slower than larger grains. Small grains also have different steeping requirements to larger grains. High screenings is associated with reduced starch deposition relative to protein.

**Staining**

Staining is a measure of grain discolouration. In many cases the effect of grain discolouration on quality is very subjective, but buyers of grain prefer to buy bright, clean grain. Grain colour on receipt at Co-operative Bulk Handling is now measured using near infra-red analysis and is presented as a score. The lower the reading the greater the grain discolouration.

Heavily stained grain requires longer storage before malting. Staining reduces the capacity of the malster to easily increase grain moisture during steeping. It may also alter the colour of the wort and in turn the colour of the beer produced.

**Malt quality parameters**

**Extract**

Extract is simply a measure of the amount of sugars available for fermentation to produce alcohol. The amount of fermentable sugars measured from a finely ground malt determines quality (Figure 30). The higher the extract level, the more alcohol that can be made per tonne of grain. Extract is presented as a percentage on a dry basis.

![Figure 30. Relationship between grain size and extractable malt](image)

The difference in extract between finely ground and coarsely ground malt is called fine - coarse difference. A difference of less than 2 per cent indicates that the grain has been satisfactorily modified. A value greater than 2 per cent generally indicates the grain was of a poor quality for malting (i.e. high viscosity or high protein).

A minimum level of 80 per cent extract is required for the export market. Malters try to achieve this level of extract with a four-day malt. In situations where extract levels are likely to fall below this level, the grain will be germinated for longer to allow more modification to occur. This reduces throughput time in the malting house and decreases plant efficiency.

**Diastase**

Diastase is a measure of the amount of diastatic enzymes available in the grain for converting starch to fermentable sugars. As the diastatic enzymes are proteins, their production is directly linked with the formation of protein in the grain. Diastase is presented in units of Windich Kolbach (WK).

Low diastase levels are associated with a low potential for fermentable extract.

**Viscosity**

Viscosity is a measure of the gumminess of the sugary solution used in the brewery. It is measured relative to water. Viscosity relates to the level of soluble α-glucans present, which
are components of endosperm cell walls. Viscosity is presented in units of centipoises (cP).

Barley with a low viscosity germinates more evenly than barley with high viscosity. As B-glucan is a component of endosperm cell walls it can inhibit the modification of starch by acting as a physical barrier to diastatic enzymes. Highly viscous malt takes longer to filter in the brewery.

Management factors affecting grain protein and malting quality

In simple terms any agronomic practice that alters grain size and/or grain protein concentration will alter the malting quality of barley. This is because of the strong linkage between grain size, grain protein and starch.

Nitrogen in the grain comes from two sources: from nitrogen taken up by the plant after anthesis and from nitrogen remobilised from senescing vegetative tissue. Grain protein concentration depends upon the amount of nitrogen in the plant and how many grains the nitrogen has to be distributed into. The environmental conditions during the grain filling period then determine how much protein and starch is deposited.

Protein is deposited more strongly than starch in the early part of grain filling (Figure 31). Any factor that shortens grain filling affects starch deposition more than protein, increasing protein concentration. These same conditions can reduce grain size, since grain size is influenced by the amount of starch deposited. Long, cool grain filling periods, on the other hand, favour starch deposition, reducing protein concentration by dilution.

Figures 32, 33 and 34 for Stirling and Franklin barley grown in 1992 across a range of sites. While relationships exist between grain protein and extract, diastase and modification, there is no relationship between grain protein and viscosity.

![Figure 31. Deposition of protein and starch during grain filling](image)

While the weather can influence the quality of the grain, agronomic practice also influences grain and malting quality. Management factors that alter the supply of nitrogen to the plant alter malting quality. Poor management leads to the production of grain with a poor malting quality. The most important management factors that influence malting potential are:

- soil type,
- time of sowing,
- rotation,
- nitrogen applied.

These factors alter nitrogen supply and potential yield. Practices that increase grain yield, without altering nitrogen supply, reduce grain protein and increase malting quality. Practices that increase nitrogen supply, without increasing grain yield, increase grain protein and reduce malting quality.

The relationship between grain protein and malting quality is clearly demonstrated in...
The choice of rotation and soil type alter the base conditions under which a crop will develop.

Paddock history is one of the most important factors affecting nitrogen supply to the crop. The nitrogen from legume organic matter not only boosts grain yield, but increases grain protein concentration. This occurs because nitrogen from organic matter is available throughout the season, boosting nitrogen uptake after anthesis and subsequently boosting grain protein. Fertiliser nitrogen applied in the first four to six weeks after sowing, however, is used by the plant in setting up grain yield potential.

Soil types are also important to the availability of nitrogen. Loams or clay soils are generally more fertile and hold nitrogen better than sandy soils. The sandy soils are more prone to leaching of nitrogen down the profile.

Time of sowing alters the potential crop yield. Sowing at the optimum time for yield will lower grain protein. Timing of nitrogen application in relation to sowing date is very important. Applying nitrogen for yield will not produce high protein grain unless there is a dry finish to the season. Use of nitrogen rates above that recommended for maximum yield will raise grain protein.

Early sowing of Franklin after a long legume ley can produce grain of low malting quality due to high nitrogen supply from the legeue rotation. Late June sowing of Stirling after several years of legume pasture is another scenario which produces lower quality grain. Late June sowing with high nitrogen applications will push up grain protein and lower malting quality.

The secret to managing grain protein in barley is to avoid planting in paddocks following long periods of legume pasture or crop, where nitrogen supply after anthesis will be high. Instead, sow malting barley as the second cereal after a legume or after canola or after a single year of legume and apply nitrogen for yield.

Industry's aim is to have all malting barley deliveries with protein (dry basis) concentration between 9 and 11.8 per cent. This will ensure the production of a consistently high quality crop between seasons for the domestic and export markets.

Environmental conditions affecting malting quality

With correct management we can set up the crop to achieve a quality target by choosing the correct sowing date, right rotation, sufficient nitrogen for maximum yield and good crop protection via weed, disease and insect control. Unfortunately we cannot control end of season environmental conditions, which in some seasons will not allow the producer to achieve desired quality limits.

Grain viscosity is related to the amount of stress a plant receives, rather than the ratio of protein and starch deposited. Viscosity is a measure of the level of β-glucan in endosperm cell walls and stress increases β-glucan. Increases in β-glucan level can be associated with a reduction in extract or a decrease in modification. Stress can lower potential malting quality.

Grain-filling in barley in Western Australia is usually associated with dry springs and transient hot spells between anthesis and grain fill. Episodes of heat stress and water stress may occur separately or together.

Moisture stress during grain-filling can increase grain viscosity. Dry finishes to the season and shallow soils with impermeable subsoils restrict moisture availability.

Periods of high temperatures after anthesis (above 30°C) affect starch deposition, but not protein.
deposition in the grain. Long or frequent periods of high temperature may increase protein concentration because no starch is deposited.

The malting potential of barley is therefore affected by the timing of these various events during grain filling. In some seasons these episodes may affect extract level, ease of modification, ability to mash the malt or grain viscosity. In other seasons the grain may be affected to a lesser degree or not at all.

It is important, therefore, to ensure the variety sown completes grain filling with the least amount of stress as possible. Late sowing of long season varieties can lead to increases in ß-glucan. Similarly, the production of large amounts of herbage for crops sown on shallow soil types will lead to moisture stress during grain filling.

Summary

- Crop management can alter malting quality.

- Any practice which increases grain protein concentration can reduce malting quality. These practices include:
  - high rates of applied nitrogen,
  - application of nitrogen after tillering,
  - late sowing,
  - sowing after periods of two or more years of legume,
  - sowing on soils which restrict moisture availability during spring.

- Aim to produce malting barley with grain protein (dry basis) between 9 per cent and 11.8 per cent. Too little grain protein (less than 9 per cent) is just as undesirable as too much grain protein (more than 11.8 per cent). The best management practice includes the following:

- Soil type: sow on soils with well structured subsoils and avoid soils prone to long periods of waterlogging.
- Time of sowing: maximise yield by sowing at the right time for the variety (Franklin in first two to three weeks May and Stirling in last two weeks May and first two weeks June),
- Rotation: sow after canola, as the second cereal after a legume or as the first cereal after one year of legume,
- Nitrogen: apply no more nitrogen than is required for maximum yield within four to six weeks after sowing,
- Disease control: use seed dressings to reduce leaf diseases and avoid paddocks with high take-all risk,
- Insect control: control aphids in high potential yield situations (more than 3 t/ha).
12. BARLEY BREEDING

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Barley breeding in Western
Australia is a joint activity
between the Department of
Agriculture and the University of
Western Australia. Barley
improvement was first
undertaken by the Department of
Agriculture in the 1930s, when
it was added to the
responsibilities of the Cereal
Plant Breeder. A dedicated
breeding program began in 1964.
This chapter outlines the
objectives of the breeding
program and how the resources
are organised to achieve these
objectives.

Features of barley relative to other cereals

Barley has persisted in
commercial cultivation for
probably 18,000 years. The origin
of the crop is in an area of
marginal winter rainfall in the
Near and Middle East, but
throughout its long history of
cultivation, it evolved into many
different types across Asia and
Africa. Barley has a wider range of
adaptation than any other cereal
crop.

In Asia and Africa, barley has
always been used for stock feed
and human food. The use of
barley for brewing alcoholic
beverages has also had a long
history with evidence from
Egyptian artefacts suggesting that
it was used for this purpose 5000
years ago. The use of barley for
stock feed, human food and
brewing, together with its wide
adaptation saw the crop spread to
six continents.

The crop is now grown at very
high latitudes (for example Alaska
64° N, Finland 67° N and Norway
70° N), and at high altitude in
Tibet and Ethiopia. Barley has a
particular reputation for
performing well in areas of low
rainfall. This is due to its rapid
maturity, and a lower water
requirement for the production of
a unit weight of grain. However,
barley will also perform well in
high productivity environments.
Barley is less tolerant of acidic
soils and cold winter
temperatures than is wheat or rye.

A number of different forms of
barley have evolved. There are
three major distinctions.

Barleys differ in the structure of
the ear with some being two-row
and others six-row. Both types
have three spikelets at each node
on the ear and each spikelet has
one floret. In two-row barley the
two lateral spikelets are sterile,
resulting in two rows of seeds on
the ear. All florets of six-row
barley are fertile resulting in six
rows of seeds when viewed from
the top of the ear. Two-row
barleys generally have larger seeds
than six-row types, but six-rows
are generally regarded as higher
yielding.

A further distinction can be made
between winter and spring
barleys. The winter barleys are
characterised by a requirement
for a period of cold to initiate
their reproductive development.
Winter barleys are typically
grown in cold climates where
they are sown in autumn, remain
dormant through the winter and
proceed with vegetative and
reproductive development in the
spring and summer. The length
of growing season required for
the crop can be 9 or 10 months.
Winter varieties are generally
higher yielding than spring
barleys and, in the UK and
Europe, a larger proportion of
the crop is sown to winter rather
than spring barley for this reason.
Winter barleys can be grown
successfully in Western Australia
from April and early May
sowings in areas on the south
coast with a long growing season.
Barley can also be distinguished by whether the seed is covered by a husk, or whether the husk threshes free during harvest. Seed without a husk is referred to as hullless or naked. These types of barley are prominent in Korea, China and Tibet where they are principally used for human food.

### Objectives for barley breeding in Western Australia

This section provides an introduction to the objectives for barley breeding, the procedures and processes for achieving the objectives are described in detail later in the chapter in the section on 'Breeding methods'.

The objectives for barley breeding in Western Australia are established in close consultation with industry. They reflect present and future characteristics required in barley varieties. The allocation of resources for achieving the various breeding objectives is consistent with the quantity and distribution of barley production in the State. In general, 40, 40 and 20 per cent of the resources are allocated to the high (450-750 mm), medium (325-450 mm) and low (less than 325 mm) rainfall regions respectively. This priority applies to the number of crosses that are made for each rainfall zone, the number of progeny evaluated in each region and the number of trial locations used in each region.

The reduced emphasis on barley breeding in the low rainfall area reflects the lesser importance of barley in this region, where crop production is dominated by wheat. While some research has shown that feed barley is often higher yielding than wheat in low rainfall areas, poor prices for feed barley relative to wheat makes it a less attractive crop to grow. In the low rainfall region, barley is principally used as an opportunity crop in seasons with late breaks and on sodic soils.

The lower emphasis on barley in the low rainfall area makes an interesting contrast to other low productivity environments such as in Western Asia and North Africa. These environments also have a Mediterranean climate, but barley is generally preferred to wheat in the low rainfall areas and wheat is preferred to barley in high rainfall areas. The difference in emphasis reflects the role of barley in Western Asia and North Africa as a staple food crop and a feed for livestock, rather than a cash crop.

Specific breeding objectives have been established for each rainfall region (Table 10). These reflect the different plant types required for adaptation to each of these regions, particularly with respect to maturity and plant height.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>High (450-650 mm)</th>
<th>Medium (325-450 mm)</th>
<th>Low (&lt;325 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>dwarf (= Skiff)</td>
<td>tall (&lt; Windich)</td>
<td>tall (&lt; Windich)</td>
</tr>
<tr>
<td>Maturity</td>
<td>medium (=Onslow)</td>
<td>early (= Stirling)</td>
<td>early (= SStirling)</td>
</tr>
<tr>
<td>Straw strength</td>
<td>strong (=Skiff)</td>
<td>strong (=Windich)</td>
<td>strong (=Yagan)</td>
</tr>
<tr>
<td>Neck strength</td>
<td>strong (=Skiff)</td>
<td>strong (=Windich)</td>
<td>strong (=Yagan)</td>
</tr>
<tr>
<td>Scald resistance</td>
<td>high</td>
<td>moderate - high</td>
<td>moderate</td>
</tr>
<tr>
<td>Net blotch resistance</td>
<td>high</td>
<td>moderate - high</td>
<td>moderate</td>
</tr>
<tr>
<td>Mildew</td>
<td>high</td>
<td>moderate</td>
<td>low</td>
</tr>
<tr>
<td>BYDV</td>
<td>high</td>
<td>moderate</td>
<td>low</td>
</tr>
<tr>
<td>Boron tolerance</td>
<td>moderate</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Tolerance of sodicity</td>
<td>high</td>
<td>high</td>
<td>high</td>
</tr>
</tbody>
</table>

< = less than  ≤ = less than or equal to  ≥ = greater than or equal to
There is a marked emphasis on selection for varieties that produce high yields in a wide range of environments. Since seasonal conditions vary considerably from one year to another, particularly with respect to the amount and distribution of rainfall, widely adapted varieties are considered essential. This is addressed in the breeding program by evaluating the yield performance of varieties over several seasons and at various locations in the rainfall regions where they are likely to be adapted.

Initially, yield tests involve few locations as there are many lines to be evaluated. The first evaluation of the yield performance of a particular generation of material may involve 800 lines, each evaluated at three locations. In the final stages of testing, the few lines being considered as potential new varieties may be evaluated at up to 50 locations each year.

In practice, wide-scale testing permits the recognition of adaptation by varieties to specific environments defined either by time of sowing, soil type, rainfall region, temperature zone or some other factor. Particular management practices may be required to maximise the performance of varieties adapted to a specific range of environments. If the particular practices are not followed, a lower level of performance may result. A good example is a variety adapted to early sowing, which may produce unacceptably low yields and small grain if not sown at the optimum time.

Inevitably, the breeder must compromise between seeking either broadly or specifically adapted varieties. Given the substantial variation in conditions from location to location and from season to season in Western Australia, the emphasis on breeding for broadly adapted varieties appears justified.

There is a greater emphasis on selection for disease resistance in the high and medium rainfall regions where diseases are more prevalent. The predominant diseases are scald, net blotch (two forms), mildew and barley yellow dwarf virus.

Disease resistance is a desirable objective for barley breeding rather than being mandatory. There are two reasons for this. While yield losses of between 20 and 30 per cent have been recorded for crops infected with scald and net blotch, losses are generally much lower than this and the diseases rarely devastate the crop. Only very early sown crops, or crops sown in paddocks where barley stubble remains from crops in previous seasons, would be likely to produce devastating epidemics.

The second reason for the lower emphasis on breeding for disease resistance is the enormous capacity for the fungi that cause scald and mildew to change (mutate) so that they are virulent on previously resistant varieties. This also applies to net blotch, but to a much lesser extent. Therefore, the breeding strategy has been to select for grain yield in the presence of the disease rather than seeking new varieties with immunity to disease.

In each rainfall zone there is a marked emphasis on the development of varieties suitable for malting and brewing. This is because premiums for Western Australian malting barley over feed barley have ranged from $20 to $30 per tonne between 1988/89 and 1993/94 and the demand for malting barley in the medium term is expected to remain strong, particularly from traditional Western Australian markets in Asia and South America.

Grain quality objectives include characteristics related to the physical and malt characteristics of the grain. The principal physical characteristics include grain plumpness, hectolitre weight and grain brightness, and for malting they include malt extract, diastatic power and wort viscosity.

**Germplasm resources**

**Sources of germplasm**

Genetic improvement of barley in Western Australia is intimately dependent on access to germplasm from interstate and overseas breeding programs. This germplasm may be accessed either directly from breeding programs or via a germplasm collection such as the Australian Winter Cereals Collection located in Tamworth, New South Wales, or its counterparts overseas.
The process of germplasm exchange relies on the cooperation and goodwill of barley breeders to gain access to elite material. Certain protocols generally apply regarding how the seed can be used and further distributed. Such agreements do not generally restrict the breeders to, or use of, the seed for research purposes such as field evaluation and use in crossing programs. The principal aim of such agreements is to establish that ownership of the genetic material remains with the organisation that was responsible for its development. A code-of-conduct is being developed for the exchange of barley germplasm with the aim of binding all signatories to a minimum protocol that recognises the basic elements of the exchange of barley germplasm and preserves the rights of the owner of the material.

New germplasm is introduced in systematic ways from various cooperators around the world or in an ad hoc fashion as the need arises. There are three principal sources of overseas germplasm from which material is introduced.

European material is obtained principally from the European Brewery Convention, who each year conduct trials on lines originating from European barley breeding programs that may be suitable for malting and brewing. Particular features of the European material that make it valuable for the Western Australian barley breeding program are excellent agronomic characteristics including straw strength and head retention, good resistance to diseases including mildew and scald and good malting quality. European programs have been a very important source of winter barley germplasm with malting quality.

Elite Canadian material is also obtained in a systematic way by introducing lines entered in the Western Canadian Cooperative barley trials, which are conducted for two-row, six row and hullless barley. These trials are used to evaluate the best lines emerging from breeding programs in the Canadian provinces of Alberta, Saskatchewan and Ontario. The feature of the Canadian material that is of most interest is malting quality.

The third principal source of germplasm is nurseries compiled by the International Centre for Agricultural Research in the Dry Areas (ICARDA). This Centre is one of the 13 organisations that have a mandate for the genetic improvement of crops internationally, and particularly in developing countries. ICARDA has the world mandate for barley breeding. A diverse collection of barleys is usually obtained each year including two- and six-rowed barley, naked barley and spring and winter types. The agronomic characteristics of this material can be extremely variable. Many lines have been resistant to mildew and scald, but some have been exceptionally susceptible to leaf rust. Many lines have also been tall and extremely susceptible to neck break.

Good cooperation exists among Australian barley breeders, which allows for the exchange of both elite lines undergoing wide scale testing and early generation material that is segregating. The free exchange of early generation material enables breeders to access crosses involving elite parents that may have been introduced into other breeding programs or which may be segregating for characters of particular interest.

Management of barley germplasm in Western Australia

The program of germplasm introduction and evaluation is organised by the University of Western Australia, under the leadership of Dr W.J.R. Boyd. New accessions of seed are obtained throughout the year for sowing in early May each year in a seed multiplication nursery at the University Field Station, Floreat. Sowing early in May increases the opportunity for discriminating among the lines for their resistance to scald and mildew, and on their time to ear emergence.

Lines that are extremely susceptible to disease or which have weak straw or bad neck break will generally not be retained for further testing unless they are reputed to have other characters of interest such as good malting quality. The accessions are allocated to one of four groups, defined by the similarity of the time to ear emergence of the accession to that of four controls; namely,
Yagan, Stirling, Onslow and Ulander, which are sown in the seed multiplication nursery. This provides the basis for field testing of the accessions in either the low, medium or high rainfall areas, or from April sowings, respectively.

Seed from the nursery is retained for three purposes. First, seed is added to the working collection of barley accessions. The working collection is a supply of seed for experimental work. A small supply of seed is added to the collection held in long term storage at 4°C. Seed up to 20 years old that has been held in this collection has remained viable. The collection held in long term storage now numbers some 6000 accessions. A further quantity of seed is passed to the breeding program for field evaluation. The Western Australian barley collection and the data that have been collected on lines held in it is an extremely valuable resource for the Western Region barley breeding program.

Parental selection

Choice of parental material to use in crosses is a crucial aspect of all plant breeding programs and is governed principally by the objectives of the program. Breeding can proceed by either of two processes known as defect elimination or germplasm development. The choice between these strategies depends on their likelihood of producing varieties suitable for commercial cultivation.

Defect elimination involves further developing an elite line that may be either deficient in particular characteristics or which may have certain undesirable characteristics. The most common instances where this applies is breeding for resistance to disease where a variety may have almost all of the characteristics required for commercial cultivation, except that it may be susceptible to disease. This problem can be addressed using a process of defect elimination with the aim of retaining in the new variety all of the desirable characteristics of the existing variety but incorporating the disease resistance of the other parent.
In breeding programs that have reached a certain stage of maturity in that the breeding material that is available is well adapted to the target agricultural area, defect elimination is often the preferred strategy. The aim then is to achieve a series of relatively small step-wise improvements by building on the germplasm already available. Several breeding programs for malting barley in Europe have reached this stage of maturity. Their varieties are high yielding, have strong straw, and good malting quality. The aim of these programs is to retain these desirable characteristics, try to improve on them, and possibly introduce new desirable characteristics.

In breeding programs that are less mature it may be recognised that there is considerable scope in some environments for improvements in grain yield, agronomic characteristics and grain quality. In these cases, existing varieties may require improvement in many characteristics both to introduce new desirable characteristics and eliminate undesirable existing characteristics. It may be possible to address all of the breeding objectives only by making a series of crosses among parents that collectively have all of the characters of interest.

The choice of parents and the best ways that they can be combined requires an extensive working knowledge of parents that are available as well as the usefulness of varieties when they are used as parents. There are marked differences among varieties in their usefulness as parents. This is a characteristic known as their combining ability. For example, some varieties may perform consistently well as parents for improving malting quality, whereas other malting quality varieties may be less useful for improving quality (see section ‘Breeding for quality’).

Crossing generates genetic variability among progeny derived from crosses between elite parents. Variability exists among the progeny for all the characters by which the parents differ. The plant breeder exploits this expression of variability by selecting progeny that combine the characters that are of interest.

### Crossing

#### Crossing strategy

The expression of genetic variability can be manipulated by the choice of parents and the manner in which they are combined. If parents are genetically similar, the genetic variability among the progeny will be smaller compared with that among progeny from crosses among varieties that genetically are markedly different. For example, crossing Franklin with Onslow is regarded as a wider cross than crossing Franklin with Tallon since Franklin and Tallon both have Triumph as a common parent, but Franklin and Onslow have no parents in common. The Franklin / Tallon cross represents a form of inbreeding and depending on the selection strategy, it may preserve, at least in part, the integrity of the Triumph background in progeny selected from the cross.

Genetic variability among the progeny can be either reduced or accentuated by crossing varieties in particular ways. The basis of all crossing strategies is the single cross, which is typically written as parent 1 / parent 2. A practical example is Forrest / Aapo, the pedigree of Onslow. In this crossing strategy, each parent has the opportunity to contribute the same proportion of their genetic characteristics to the progeny.

Genetic variability in the progeny is minimised by backcrossing, which involves successive crossing to a recurrent parent. This is a desirable strategy for introducing a single, simply inherited characteristic into a new variety. These crosses typically are written as donor/x*recurrent, where recurrent is the adapted parent, donor is the donor parent with the characteristic to be introduced into the recurrent parent and x is the number of backcrosses performed. A specific example might be Morrell/3*Franklin, the aim of which would be to recover in selected progeny the desirable yield, agronomic and quality characteristics of Franklin, but with the naked grain character of Morrell.

As the number of backcrosses increases, so too does the contribution of the genetic characteristics of the recurrent parent to the progeny. In the example Morrell/3*Franklin, 87.5 per cent of the genetic constitution of the progeny are expected to be contributed by
Franklin. That is, progeny will substantially reflect the characteristics of Franklin, with a partial contribution of the characteristics of Morrell.

Top crossing involves intercrossing of three parents. This may be written parent A/parent B/parent C. This is achieved by crossing parent A with B, sowing the seed that is harvested from the cross and crossing to these plants using parent C. In progeny from such a cross, 25 per cent of the genetic constitution is contributed by parents A and B, and 50 per cent is contributed by parent C. These crosses are used commonly in the Western Australian barley breeding program. The cross Stirling/Harrington/Skiff is a good example. The objective of this cross was to develop progeny that express the desirable malting quality characteristics of Stirling and Harrington, the wide adaptation of Stirling to the low and medium rainfall area, and the grain plumness of Stirling with the wide adaptation and strong straw of Skiff.

An important and commonly used variation of the top crossing strategy is intercrossing between F₁ lines. This may involve three or four parents. The type of crosses performed may be A/B/C/D, or A/B/A/D. In the first example, each parent is expected to contribute 25 per cent of its genetic constitution to the progeny. In the second example, a common parent has been used to generate both F₁’s before intercrossing them. Therefore, this parent is expected to contribute 50 per cent of its genetic constitution to the progeny, and the other parents 25 per cent. (See following section ‘Breeding methods’).

**Crossing technique**

In barley, both the male and female parts of the plant are enclosed within each floret. This contrasts with other plants where the male and female plant parts may be physically separated on the same plant (for example, maize where the silks are the female parts and the tassels are the male parts), or where male and female parts occur on different plants (for example, some plums and pawpaws). The inclusion of both the male and female parts with each floret predisposes barley to self-fertilisation. That is, pollen is released from anthers, which fertilises the ovary within each floret. There is minimal opportunity for natural cross pollination since it is difficult for the pollen to escape from the florets.

Artificial hybridisation of two parental lines must interrupt the natural fertilisation process by emasculating a plant that will serve as the female parent (see photo of barley floret). This can be achieved by physically removing all the anthers from each floret before they release pollen. The ear is then bagged to prevent fertilisation by pollen from other sources.

Several days after emasculating, the female plant parts are usually receptive to pollination from the male parent. Pollen is obtained from the male source immediately before, or just as anthers burst to release their pollen. Pollination of the female parent is achieved by removing the bag that was applied following emasculation and dusting the female parts in each floret with pollen from the male parent. The bag is then reapplied to the ear to prevent any possibility of pollination from other sources.

The first generation seed grows in the floret in the usual way. These hybrid seeds often show dormancy and low germination. It is often necessary to employ techniques such as heat treatment of the seed and germination on moist blotting paper to obtain higher germination percentages.
Breeding methods

Two breeding methods are being used by the barley breeding program in Western Australia to develop new varieties. These methods are modified pedigree breeding and a doubled haploid breeding procedure.

The former procedure is well-known, having first been described in 1957 and applied in Western Australia since 1965 for the development of new barley varieties. The modified pedigree breeding procedure has been widely used throughout Australia in breeding programs for barley and many other crops including wheat, oats and lupins.

The use of doubled haploids for barley breeding is a much more recent development, with a dedicated program being initiated in Western Australia in 1993. The flow of material from one generation to the next in each of these programs is illustrated in Table 11.

The generations following crossing are identified by a subscript number attached to the symbol F, which together represent the filial generation. The seed produced by crossing is the F₁ seed and plants grown from the F₁ seed are the F₁ plants. Subsequent generations of seed and plants are labelled consecutively.

The breeding method that is most appropriate for a particular crop is substantially dictated by whether the plant is naturally self- or cross-pollinating. This will generally determine the opportunities for completing crosses and developing populations of lines within which selection for improved varieties can take place.

<table>
<thead>
<tr>
<th>Generation</th>
<th>Trial</th>
<th>Testing</th>
<th>Selection</th>
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<tbody>
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<td>F₁</td>
<td></td>
<td>Glasshouse</td>
<td></td>
</tr>
<tr>
<td>F₂</td>
<td>BP1</td>
<td>Single plant selection</td>
<td>Straw strength</td>
</tr>
<tr>
<td>F₃</td>
<td>BC1</td>
<td>Seed increase</td>
<td>Straw strength, quality</td>
</tr>
<tr>
<td>F₄</td>
<td>B11</td>
<td>3 Sites</td>
<td>Yield, quality</td>
</tr>
<tr>
<td>F₅</td>
<td>B12 and BP2</td>
<td>4 sites</td>
<td>Yield, quality</td>
</tr>
<tr>
<td>F₆</td>
<td>BC2</td>
<td>Seed increase</td>
<td>Straw strength, quality</td>
</tr>
<tr>
<td>F₇</td>
<td>B21</td>
<td>3 sites</td>
<td>Yield, quality, agronomy</td>
</tr>
<tr>
<td>F₈</td>
<td>B22</td>
<td>5 to 8 sites</td>
<td>Yield, quality, agronomy</td>
</tr>
<tr>
<td>F₉</td>
<td>Stage 3</td>
<td>17 sites</td>
<td>Yield, quality, agronomy</td>
</tr>
<tr>
<td>F₁₀-12</td>
<td>Stage 4</td>
<td>Up to 45 sites</td>
<td>Yield, quality, agronomy</td>
</tr>
</tbody>
</table>
As barley is a self-fertilising crop, the varieties in commercial production are true-breeding from one generation to the next. That is, the genetic characteristics of a variety remain unchanged from one generation to the next. However, for at least the first five generations of self-fertilisation after crossing, lines are not true-breeding since lines in each generation contain different combinations of the genetic information contributed by both parents. This is due to continual rearrangement of the chromosomes within each line so that they express different genetic characteristics. A consequence of the variation between generations is that when pedigree breeding procedures are used, selection of the line that enters commercial production must be delayed until genes become fixed and lines can be selected that are true-breeding.

**Modified pedigree breeding**

Genetic variation among lines developed using a pedigree breeding procedure is expressed in the F₂ and subsequent generations. For example, a cross between a tall, malting quality variety such as Franklin and a dwarf, feed variety such as Skiff will produce plants in the F₂ generation that exhibit various combinations of the genetic characteristics of both parents. This variation can be exploited by retaining for further testing those plants that express the desirable characteristics being sought for the target environment such as a dwarf, malting type.

The number of single plant selections from each cross typically varies between 12 and 160 depending on the agronomic characteristics of the plants and the likelihood of the cross producing new varieties. The principal characteristics selected in the F₂ generation are straw strength, neck strength and height. Selection for yield and other traits is not possible because their measurement on single plants generally bears no resemblance to performance in later generations.

Each single plant selection is threshed individually, generally yielding between 10 and 30 g of seed, which is used to sow the F₃ generation in small plots. Since little seed is available, the evaluation of lines cannot be replicated either within or across sites. In the F₃ generation selection in spring is for maturity and resistance to disease.

Before harvest, those lines with weak straw or high levels of head loss due to breakage of the straw just below the ear are discarded. Up to one-half of the lines in each cross may be discarded because of weak straw and neck break. The remaining plots are harvested and the grain is subjected to measurements of grain plumpness and hectolitre weight. A further one-half of the lines may be discarded, particularly those with thin grain. A subsample of the grain from the remaining lines is submitted to the Department of Agriculture's Grain Products Laboratory for preliminary evaluation of malting quality.

The F₃ plots are used to focus further evaluations on lines with strong straw and plump grain. The trials also serve as a seed multiplication generation. The F₃ generation is a particularly important one in the barley breeding program since it establishes which crosses will be emphasised in subsequent tests. Poor decisions in this generation may result in inferior material being retained for testing, which has no prospect of generating new varieties.

Between 400 and 2500 g of seed may be produced from the F₃ plots. This seed is used to sow trials at three locations with two replications. Decisions on lines to be retained for further testing are based on the yield results from the F₄ generation and the physical grain and micromalt data from the F₅ generation. Only 25 per cent of the lines may be retained for further testing. A similar series of trials is conducted in the F₅ generation, except that the trials are usually conducted at an additional location and larger plots are used to get a more precise evaluation of yield performance.

Identification of elite lines in the F₅ generation is based on the combined yield data from the F₄ and F₅ generations and the combined quality data from the F₃ and F₄ generations. By the fifth generation, lines are near to true-breeding and the data on their performance in the F₃, F₄ and F₅ generations is used to determine in which crosses, and from which F₄ selections from those crosses, reselections will be taken to develop true-breeding lines for detailed evaluations. Reselection is generally practised in only 20 per cent of the lines entered in the F₅ trials.
Breeding using doubled haploid barley lines

Anther culture and other procedures can be used to produce true-breeding lines from hybrid material in as little as eight months. Anthers are the male sexual organs of the plant. They contain pollen cells, which in barley contain half of the genetic compliment of a fertile barley plant. In normal fertilisation, these chromosomes combine with the seven chromosomes in the ovule, restoring the full chromosome set required for fertile plants.

Anther culture involves the generation of plants from immature pollen cells, bypassing fertilisation and growth of the seed. Pollen cells and the plants derived from them are described as haploid as they contain only half the chromosomes of the parent. Haploid plants are of little use as they are sterile and will not set seed. However, if the chromosomes of a haploid plant are duplicated, the normal, diploid chromosome number is restored and the plant will be fully fertile. In barley, spontaneous chromosome doubling occurs in about 70 percent of plants generated from pollen cells. Such plants are called doubled haploids.

If anthers are cultured from plants grown in the F1 or F2 generations, the genetic constitution of the doubled haploid lines is fixed by the spontaneous doubling of each chromosome. The new lines are then 100 percent true-breeding from one generation to the next and there is no delay in identifying lines that could enter commercial production.

Varieties differ markedly in their responsiveness to anther culture and this is one of the most important factors affecting the technique's efficiency for barley breeding. Some varieties such as Chebec and Stirling respond extremely well, producing about 120 and 40 green plants respectively, for every 100 anthers cultured. By contrast, it is relatively difficult to generate green plants via anther culture from parents such as Franklin and Harrington. Crosses involving unresponsive parents are avoided in the anther culture program.

Since doubled haploid lines are true-breeding there is no need to develop and evaluate bulked lines as occurs on the modified pedigree procedure in the F3, F4 and F5 generations. Seed from doubled haploid plants can be multiplied and entered in trials to evaluate yield and quality together with reselections from early generation bulked lines.

Evaluation of true-breeding lines

For lines developed by the modified pedigree breeding procedure, the cycle of seed increase and yield and quality evaluation is repeated on the true breeding lines in the F6, F7 and F8 generations, using similar selection criteria and intensities to those adopted for the F3, F4 and F5 generations during which lines were segregating.

Similarly, the seed of lines developed through anther culture are multiplied and testing is performed for yield and quality characteristics following the same strategies as for the F6, F7 and F8 lines.

True-breeding lines that perform well in these tests are promoted to wide-scale trials conducted by the Crop Variety Testing (CVT) program. These trials are conducted at 17 to 45 locations throughout the agricultural area using long plots that give accurate estimates of the yield performance of crossbred lines relative to controls. Grain samples from the CVT trials are used by the Grain Products Laboratory for macro-scale quality tests. Additional trials are conducted to produce seed of potential malting varieties and appropriate controls for evaluation of malting quality by domestic maltsters.

Testing procedures

The testing performed in each generation is determined by the number of lines to be evaluated, the heritability of the characteristics of interest, the availability of supplies of seed for conducting trials and the likelihood that variation will be expressed among lines for particular characteristics.

Breeding for yield and adaptation

The principal locations for evaluation of grain yield, agronomic characteristics and quality during the initial stages of the breeding program are Mt Barker (high rainfall), Wongan Hills (medium rainfall) and Newdegate (low rainfall). In later generations, trials are conducted at locations in each region-zone cell. Since there are many lines to be evaluated at many locations, there is a high degree of mechanisation in most field operations.
Trials in the barley breeding program are sown using a cone seeder at a rate of approximately 1000 plots per hour. Small plots are used initially, either 5 or 10 m long. Elite lines in later generations, for which larger supplies of seed are available, are evaluated in plots 25 m long.

Management practices for trials follow best local practices. That is, fertilisers and herbicides are applied to the extent that the performance of the crop is not limited by either nutrient deficiencies or excessive competition from weeds. In practice, less than optimum levels of management are sometimes achieved. It is always important to recognise instances where the results from trials may be misleading with respect to the performance of varieties for yield and other characteristics. These results may be either discarded or interpreted in isolation from the main body of results.

Mobile units operated by the barley breeding program, comprising two small plot harvesters and a truck, travel to the various locations to harvest field trials. Each harvester operator is able to harvest 800 plots per day.

Breeding for disease resistance

For some diseases, such as take-all and rhizoctonia, no deliberate selection is made. There are two reasons for this. First, there are technical difficulties assessing damage to roots by disease. It is difficult to get repeatable infections and screening of the roots can be a laborious process.

Second, the levels of resistance that are available to these diseases are small in the case of take-all and none have been observed for rhizoctonia.

For scald and net blotch, screening of parental lines, introductions and fixed lines reselected from elite early generation bulks is conducted at Wongan Hills and Mt Barker. Disease nurseries are sown as early as possible in the growing season to encourage the development of disease. One-metre-long rows are sown. Straw collected in the previous season, which is infected with either scald or net blotch (but not both diseases), is spread across the disease nursery to initiate the infection.

The nurseries are scored for disease development on several occasions during the growing season. This strategy permits the assessment of both the degree and rate of disease development.

Mildew nurseries are established in South Perth. The reliability of infection can be variable. Establishment of nurseries at other locations has generally not been successful because of the dominance of other diseases, and particularly scald, which make scoring the mildew infection difficult.

Specific nurseries are not established for infection by barley yellow dwarf virus. Many introductions grown at locations on the south coast are susceptible or very susceptible and they will often be eliminated from the program. Lines in the F3 generation of the program are eliminated from the program if they are susceptible.

Breeding for quality

Breeding for quality is a complex process. There are many characters to be manipulated, and as a consequence, large breeding populations must be screened to identify those few lines that combine all the required quality characteristics. Screening in the Grain Products Laboratory is generally a labour intensive and time consuming process. In the case of malting quality, special equipment is required for micromalting and for measuring characteristics of the resulting malt and wort. While many important advances have been made to introduce more rapid tests of malt quality, sample throughput is such that only a subset of the material being evaluated in the breeding program can be tested for quality.

Selection of parent material is crucial for improvement of grain quality, and particularly suitability for malting. Most of the improvements in malting quality throughout the world can be traced to a small number of varieties. This suggests that good malting quality is achieved in a new variety only if it has a particular combination of genes that confer good quality and that any disruption of these elite combinations in new varieties is likely to lead to inferior quality.

Some barley breeders refer to hallmark germplasm in recognition of the particular role of certain varieties for improving malting quality. In Europe, the variety Trumpf was developed in Czechoslovakia as a result of mutation of the variety Valticky. Trumpf was subsequently widely grown in other European
countries where it was renamed Triumph. Triumph was grown in Tasmania until recently and it remains the most widely grown variety in New Zealand. Crossing with Triumph has produced a series of varieties with good malting quality (Table 12).

In Canada and the USA a series of new varieties has been developed using Klages, which became the malting and brewing industry standard in the USA during the 1970s, particularly because of its high level of enzymes in the malt (Table 13).

This characteristic is reflected in all of the derivatives of Klages that have been accepted by the malting and brewing industries in Canada and the USA. Furthermore, high diastatic power in the Canadian varieties has earned them an important reputation in export markets. The development of long season malting varieties for Western Australia is based on winter barley varieties from the UK that have been derived from Maris Otter (Table 14). In Western Australia, the winter malting barley program is in its infancy and many questions have yet to be answered concerning the progress that can be made towards the development of malting barley varieties suitable for April sowings on the south coast. Some evidence suggests that the development of lines with plumg grains and which consistently have acceptable grain protein levels and good malting quality may be a difficult challenge.

### Table 12. Malting barley varieties derived from Triumph

<table>
<thead>
<tr>
<th>Country of origin</th>
<th>Variety</th>
<th>Pedigree</th>
<th>Year of release</th>
</tr>
</thead>
<tbody>
<tr>
<td>Czechoslovakia</td>
<td>Triumph</td>
<td>Diamant/14029-64-6</td>
<td>1985</td>
</tr>
<tr>
<td>UK</td>
<td>Blenheim</td>
<td>Triumph/Egmont</td>
<td>1985</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Prisma</td>
<td>Triumph/Cambrinus//Piccolo</td>
<td>1985</td>
</tr>
<tr>
<td>Germany</td>
<td>Alexis</td>
<td>Triumph/St1622</td>
<td>1986</td>
</tr>
<tr>
<td>France</td>
<td>Natasha</td>
<td>Triumph/Aramir</td>
<td>1986</td>
</tr>
<tr>
<td>Germany</td>
<td>Cheri</td>
<td>Triumph/Medusa/Diamant</td>
<td>1987</td>
</tr>
<tr>
<td>Tasmania</td>
<td>Franklin</td>
<td>Triumph/Shannon</td>
<td>1989</td>
</tr>
<tr>
<td>Queensland</td>
<td>Tallon</td>
<td>Triumph/Grimmet</td>
<td>1990</td>
</tr>
<tr>
<td>Queensland / WA</td>
<td>Trumper</td>
<td>Triumph/Grimmet</td>
<td>1994</td>
</tr>
</tbody>
</table>

### Table 13. Malting barley varieties derived from Klages

<table>
<thead>
<tr>
<th>Country of origin</th>
<th>Variety</th>
<th>Pedigree</th>
<th>Year of release</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saskatchewan</td>
<td>Harrington</td>
<td>Klages/3/Gazelle/Betzes/Centennial</td>
<td>1981</td>
</tr>
<tr>
<td>Washington</td>
<td>Andre*</td>
<td>Klages/Zephyr</td>
<td>1985</td>
</tr>
<tr>
<td>Washington</td>
<td>Lewis*</td>
<td>Klages/Hector</td>
<td>1985</td>
</tr>
<tr>
<td>Manitoba</td>
<td>Ellice*</td>
<td>CI5791/Pland//Betzes/3/Betzes/Pirolene/4/Akka/5/</td>
<td>1986</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>Manley</td>
<td>Norbet/Hector//Klages</td>
<td>1991</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>Stein*</td>
<td></td>
<td>1992</td>
</tr>
</tbody>
</table>

* These varieties produce good malts but were not accepted as malting grade varieties by the malting and brewing industries in Canada or the USA.
Table 14. Malting barley varieties derived from Maris Otter

<table>
<thead>
<tr>
<th>Country of origin</th>
<th>Variety</th>
<th>Pedigree</th>
<th>Year of release</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>Maris Otter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>Halcyon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>Waveney</td>
<td>Halcyon/Palamino</td>
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<tr>
<td>UK</td>
<td>Pipkin</td>
<td>Sergeant/Maris Otter</td>
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<tr>
<td>UK</td>
<td>Puffin</td>
<td>Igri/Athos/Maris Otter</td>
<td></td>
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</table>

rather than obtaining definitive assessments of the potential of the lines to produce good quality malts. Grain sample size varies between 50 and 500 g for micro-scale tests. Macro-scale tests are performed to produce laboratory data that reflect the absolute values of malt and wort characteristics. Macro-scale tests are typically performed on 5 kg samples. Commercial-scale tests are performed on 20 t lots of grain.

The intensity of testing genetic material increases as it progresses through the breeding program. Physical grain and malt characteristics are determined in all generations except the F5. This strategy applies intense selection pressure for plump grain, high hectolitre weight, high malt extract, high diastatic power and low wort viscosity. Approximately 2500 samples are micromalted each year, which generates 18,000 measurements of malt and wort characteristics.

Industry assessment of malt quality of potential new varieties commences with macro-scale tests conducted by domestic malsters on grain samples from up to 10 sites. These samples are generated in specially conducted trials aimed at providing grain samples that meet standard receival specifications for protein, plumpness and colour.

Those potential varieties that perform well in the macro-scale tests are grown together with a standard variety to produce lots of grain from up to five locations.

The grain is malted by Joe White Maltings Ltd using standard protocols to evaluate processing characteristics and malt quality. The malts are subsequently used by the Swan Brewery Co Ltd to evaluate brewing characteristics. The industry protocol for commercial-scale evaluation requires that the new malting varieties must have superior malting and brewing characteristics in two out of three years of commercial evaluation.
## Department of Agriculture District Offices

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<th>Location</th>
<th>Address</th>
<th>Phone</th>
<th>Fax</th>
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<tr>
<td>Albany</td>
<td>116 Albany Highway</td>
<td>(098) 42 0500</td>
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<td></td>
<td>Albany WA 6330</td>
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<tr>
<td>Broome</td>
<td>cnr Weld and Frederick Street</td>
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