

# BARLEY

## Growth & Development

This book describes the growth and development of the barley plant from germination to grain filling.

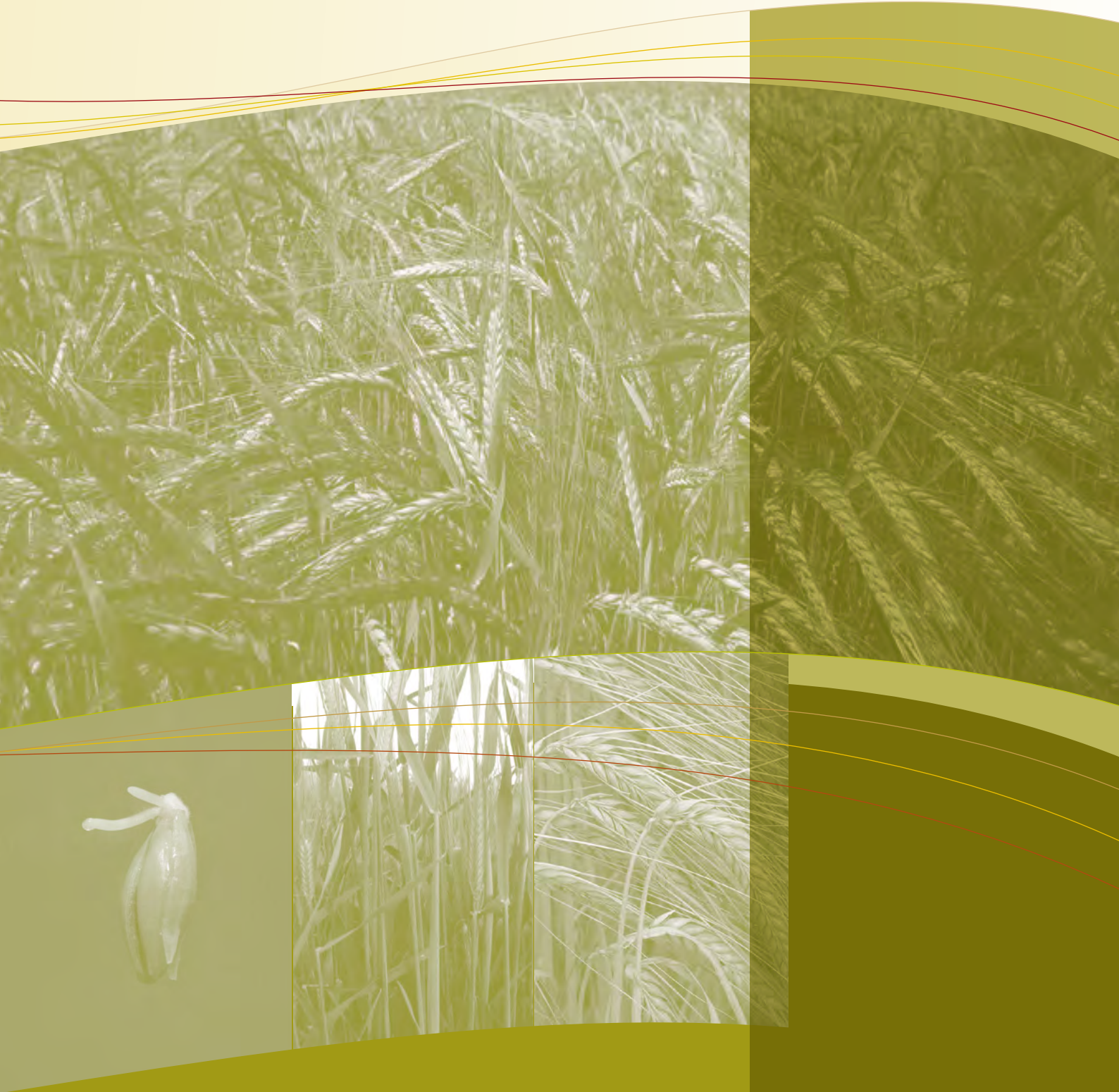
The environmental factors and management actions that influence each growth stage are also discussed.







# Barley growth & development



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# Contents

<b>Acknowledgments</b>	<b>ii</b>	<i>Sowing implements and seed placement</i>	23
<b>Preface</b>	<b>v</b>	<i>Coleoptile length and sowing depth</i>	23
<b>Introduction</b>	<b>1</b>	<i>Plant population</i>	23
Growing barley	1	<b>Chapter 2.</b>	
Barley types	2	<b>Vegetative growth and plant development</b>	<b>25</b>
Life cycle	4	Vegetative growth (Z10–Z31)	26
The barley grain	5	Factors affecting vegetative growth	31
The barley plant	6	Factors affecting plant development	35
References and further reading	9	References and further reading	38
<b>Chapter 1.</b>		<b>In the paddock</b>	<b>39</b>
<b>Germination, emergence and establishment</b>	<b>11</b>	<i>Examining the root system</i>	39
Germination (Z00)	12	<i>Assessing plant growth stage</i>	39
Emergence (Z07)	13	<i>Tiller counts</i>	40
Establishment (Z10)	13	<i>Dry matter assessment</i>	41
Factors affecting germination, emergence and establishment	13	<i>Monitoring for pests, diseases and injury</i>	41
References and further reading	20	<i>Thermal time</i>	42
<b>In the paddock</b>	<b>21</b>		
<i>1000-grain weight</i>	21		
<i>Graded versus ungraded seed</i>	21		
<i>Treated and untreated seed</i>	21		
<i>Calculating the germination percentage</i>	22		
<i>Calculating sowing rates</i>	22		

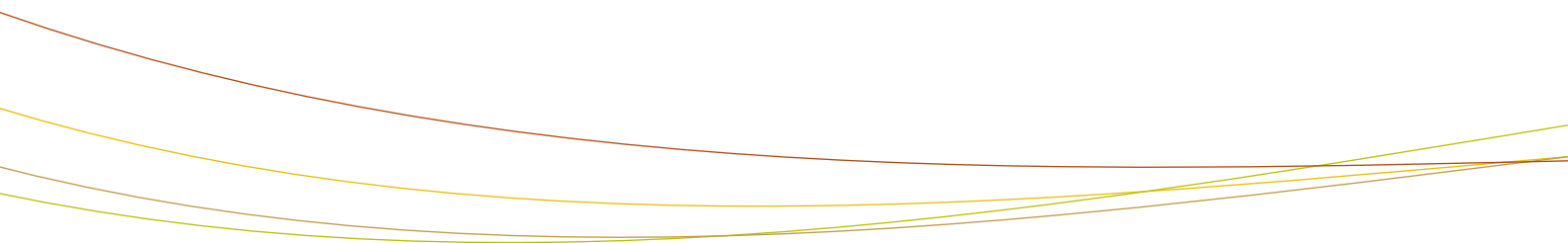
<b>Chapter 3.</b>		<b>Chapter 4.</b>	
<b>Reproductive development</b>	<b>43</b>	<b>Grain development</b>	<b>57</b>
Reproductive development (Z13–69)	44	Grain development (Z71–Z90)	58
Factors affecting reproductive development	48	Factors affecting grain development	60
References and further reading	53	Canopy management	63
<b>In the paddock</b>	<b>55</b>	Measuring crop performance	65
<i>Identifying Z30 (the awn primordia stage)</i>	55	References and further reading	67
<i>Nitrogen topdressing</i>	55	<b>In the paddock</b>	<b>69</b>
<i>Flowering</i>	56	<i>Estimating yield</i>	69
<i>Modelling flowering time</i>	56	<i>Calculating harvest index</i>	69
		<i>Calculating water use efficiency</i>	70
		<b>Glossary</b>	<b>71</b>

# Preface

This book describes the growth and development of the barley plant from germination to grain-filling. The environmental factors and management actions that influence each growth stage are a practical reference for managing crops.

The aim of *Barley growth and development* is to link plant physiology and crop management. It will help agronomists and farmers to understand the life cycle of the barley plant and the factors that influence growth and development, and to identify the growth stages of the plant. This knowledge can then be applied to crop management to maximise yield and profit.

There are four chapters in the book covering the progression of key stages in the life cycle of the barley plant, its growth and management. Included in each chapter are practical exercises to demonstrate how knowledge of plant physiology can be applied in the paddock.





# Introduction

by Phil Bowden, Tim McNee and Neil Fettell

## Growing barley

Barley (*Hordeum vulgare*) is a widely grown and highly adaptable winter cereal crop that is used mainly for stock feed and the production of malt for the brewing industry.

Barley is an annual plant that has been selected from wild grasses. It is thought to have been an important food crop from as early as 8000 BC in the Mediterranean/Middle East region.

Because of barley's tolerance of salinity, by 1800 BC it had become the dominant crop in irrigated regions of southern Mesopotamia, and it was not until the early AD period that wheat became more widely grown.

Barley is the second-largest grain crop in Australia. Over the last 5 years Australian barley farmers produced an average of 7.5 million tonnes of grain per year, of which almost 70% was exported.

Australia is the second-largest exporter of barley, contributing almost 30% of the world's barley trade. Saudia Arabia, Japan and China are large importers of barley, and these markets are growing rapidly.

## New South Wales production

In NSW barley is the most important winter crop after wheat. Around 9.5 million tonnes of barley was produced in Australia in 2005, of which 2 million tonnes was produced in New South Wales.

Barley can grow in almost all areas of the State where cropping is possible (Figure i).

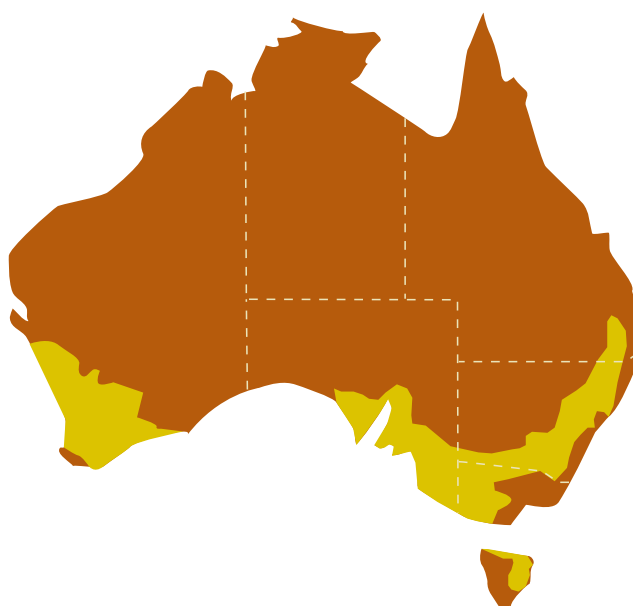


Figure i: Barley growing areas of Australia. Source: Industry & Investment NSW

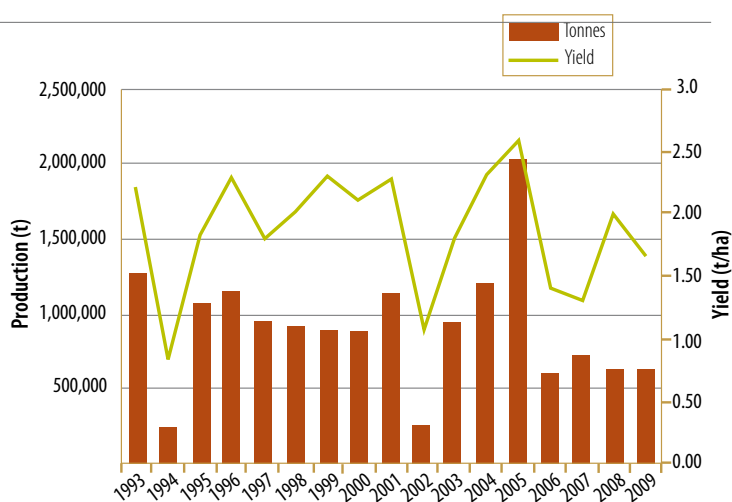


Figure ii: NSW barley production for 1993–2009. Source: Scott (2009)

Barley is more salt-tolerant than wheat and therefore can be more suited to saline soils. However, it is sensitive to soil aluminium.

The level of production of barley is sensitive to seasonal conditions and to the price of barley relative to that of wheat, sorghum and other grain crops. The average yearly production of barley during the 1990s in New South Wales was about 900,000 tonnes, with an average yield of about 1.9 t/ha (Figure ii). Production peaked in 2005, with production of around 2 million tonnes and an average yield of 2.57 t/ha.

## Barley types

There are two forms of barley, determined by the number of rows of grain along the head. Two-row barley types have only one fertile spikelet per side of the head. In six-row barley, all three spikelets per side of the head are fertile.

Two-row types are the most commonly grown. The two-row barleys can be used for malting, human food or stock food, with the quality required and the price varying for each end-use. The only current use of the grain of six-row barley is for stock feed. It is generally sown for grazing only.

## Malting barley

The malting process involves germinating the grain (Figure iii), so grain quality is very important. Because each variety of barley has different malt characteristics, only some varieties of two-row barley are used in the domestic malting industry.



Figure iii. Germinating barley for malting.  
Source: Industry & Investment NSW

Maltsters require large, plump grains with high carbohydrate content and high germination capacity. The maltster uses the grain protein level to estimate the amount of potential soluble carbohydrates. The higher the protein, the lower the potential soluble carbohydrate level, and the less acceptable the grain is for malting.

Any grain that is affected by conditions that might contribute to poor germination will not be accepted by maltsters. Such grains include pinched or small grain, black-tipped grain, cracked grain, over-dried grain, skinned grain and weevil-damaged grain, as well as grain that has already started to germinate (rain-damaged grain).

Maltsters and brewers require bright-coloured barley for the production of malt and brewed products. Poorly coloured or stained barley will be bought only 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 (as there is a higher level of wastage), poor flavour, over-foaming and reduced shelf-life of the beer produced from it.

Moisture content is also important in malting barley, particularly when it is being stored for long periods of time. Moisture levels above 12.5% will promote fungal growth and cause problems.

The malting process requires both consistent quality of the barley and varietal segregation, as each variety will malt differently. Australia has a reputation for supplying barley with consistent quality specifications. International malting barley buyers know that when they source barley from Australia, receival standards have been applied consistently across all deliveries. This ensures that protein, screenings, moisture levels, and other quality factors are kept at acceptable levels. Protein is arguably the most important factor when marketing malting barley. The ideal protein range is 9.5% to 11.0%. The use of barley with protein above 11% will result in lower malt extract values, while barley with protein below 9.5% is likely to give malts too low in enzymes and free amino nitrogen.

Other quality aspects considered by malt barley buyers include grain plumpness and weight. Plump grains of an even size are preferred to ensure even germination during steeping. Small grains and cracked grains must be removed prior to malting. Skinned grains may fail to germinate.

### Barley for other human foods

The trade for barley products (such as flour, flakes or grits), other than malt, for human consumption is small. For these products grain quality standards are not quite as tight as for malting. Most of the barley used for food is milled and processed, so it should be of a similar standard to wheat. Development of high fibre barley and low gluten barley varieties are currently being researched to increase the possible markets for Australian barley.

### Barley for stock feed

Barley is used as stock feed, especially in the intensive pig, poultry, dairy and beef industries. This demand is met by varieties specifically grown as high-yielding feed types (e.g. Tilga) as well as grain that does not meet the quality requirements for malting or human food.

Barley can be sown as a dual-purpose crop (i.e. for grazing by livestock and for grain). Barley seedling growth is vigorous and therefore quick to produce enough dry matter for grazing. Its recovery after grazing is good, provided that the developing head is not grazed. When grazing barley crops, care must be taken in the use of pesticides on the seed or in the crop to observe the withholding periods for grazing or cutting for hay/silage.

For feed barley the three most important factors considered by buyers are: test weight (kg/hL), moisture content (12.2%) and screening percentage, insect damage and weed seed contamination. High screenings can indicate pinched grain that is high in fibre/protein and low in carbohydrate.

Moisture levels are important for storage reasons. Feed barley is often stored for long periods, and excessively moist barley will decline in quality owing to the growth of fungi during storage. High moisture levels increase the risk of 'hotspots' and spontaneous combustion.

Protein is a minor consideration for buyers of feed barley, particularly for consumption by ruminants, 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% and up), then protein level is otherwise of little consequence.

### Winter and spring varieties

Barley grown in NSW can also be divided into winter and spring types. The main difference between the two is that winter barleys need a period of cold temperature (vernalisation) to initiate reproduction, whereas spring barleys do not have a cold requirement.

#### *Spring barleys*

The vast majority of barley varieties grown in NSW are spring barleys. Spring barleys grow and develop in response to increasing temperature and photoperiod (daily hours of light). They do not have a vernalisation requirement to initiate flowering. It is very important to sow spring-type barleys at the recommended time to minimise the risk of frost damage during flowering. Recommended sowing times are published each year by Industry & Investment NSW in the *Winter crop variety sowing guide*.

#### *Winter barleys*

Winter barleys are used in the mixed farming zones. They need to experience a period of cold temperatures, between 0 and 10°C, to trigger a switch from vegetative growth to reproductive growth. This cold requirement is known as vernalisation. Varieties need different periods of vernalisation, so it is important to take this into consideration when selecting a variety. The cold requirement allows winter barley varieties to be sown earlier than spring types – from February to early April for grazing.

## Life cycle

The growth and development of the barley plant is a complex process. During the life cycle of the plant, many of the growth stages overlap, and while one part of the plant is commencing development, another part may be towards the end of development and changing little, at a minimum rate (Figure iv).

### Zadoks decimal growth scale

Effective crop management depends on being able to identify the growth stage of the crop. A growth scale provides a common reference for describing a growth stage. It enables better communication among farmers, agronomists, researchers and other agricultural professionals. It is important, for example, in the timing of herbicide/fungicide and fertiliser applications.

A number of growth scales are in use around the world, with the Feekes, Zadoks and Haun scales the most widely applied. Growth stages are denoted in a number of ways, including by GS (growth stage) and DC (decimal code). In this book, the Zadoks growth scale is used, as indicated by Z (Table i).

Zadoks is a decimal growth scale proposed by J Zadok, T Chang and C Konzak in 1974. Growth stages are recorded with two digits, the first indicating the primary growth stage and the second the number of plant parts in secondary stages of development.

There are 10 primary growth stages, numbered from 0 to 9. Each primary growth stage is divided into 10 secondary growth stages that indicate the number of plant parts on the main stem, extending the scale from 00 to 99. For example, Z15 indicates a seedling plant with 5 fully developed leaves on the main stem, whereas Z24 indicates a plant with a main stem and 4 tillers.

The growth scale records only leaf development on the main stem. Leaves are counted when they are fully emerged, when the ligule is visible.

Several of the growth stages occur together, so a plant may have more than one decimal code at the same time. For example, a plant may be producing leaves and tillering at the same time and so could have a code of Z15,22, meaning that it has 5 leaves on the main stem and 2 tillers.

Stem elongation is measured by counting the swollen nodes or 'joints' that can be felt on the main stem.

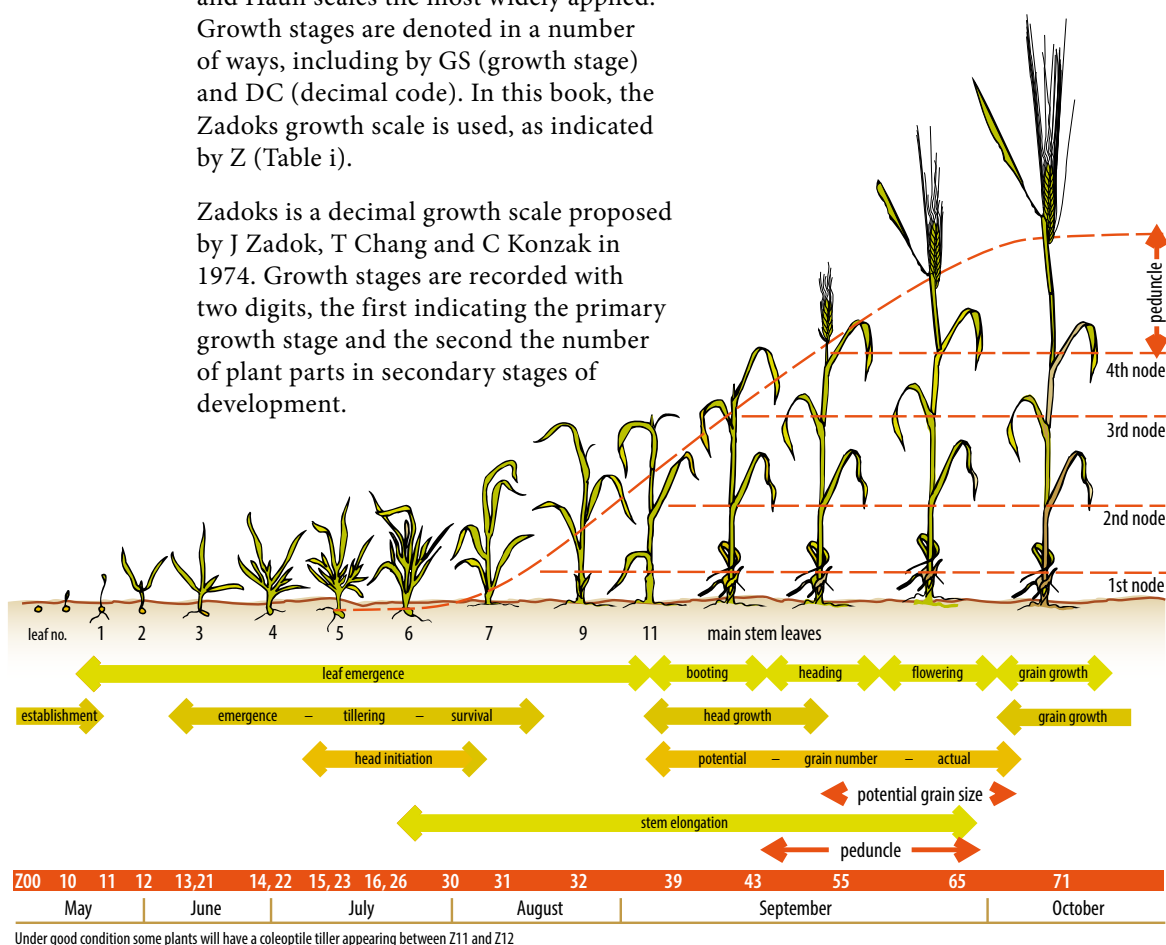


Figure iv. Life cycle of a barley plant

Barley may start flowering while the head is in the boot, so this stage will not be visible. A plant at this stage would have a code of Z43,61. Awn emergence can be used to as an indicator for anthesis in barley. However, if accuracy is important, the spikelet needs to be opened and the stamens observed.

Where appropriate, throughout *Barley growth and development* a Zadoks reference is provided for the development stage under discussion. The Zadoks decimal growth scale is provided in Table i.

## The barley grain

The barley grain is the reproductive unit of the barley plant as well as the end-use product (Figure v). A barley grain can be broadly divided into three components (Figure vi):

- husk
- endosperm
- embryo (the young plant, including the coleoptile, three or four embryonic leaves, and the rootlets).

In most varieties, the proportion of each component of the grain is 7% to 13% husk, 70% to 80% endosperm and 2% to 5% embryo.

Once filled, the barley grain is 70% carbohydrate, and 97% of this is starch (Figure vi). The protein content is between 8% and 15%, depending on the final grain weight; this equates to 4 to 10 mg. The type and content of protein and of other constituents such as cell walls can significantly affect the brewing process and final beer quality. Therefore, only specific varieties are suitable for malting.

### Husk

The outer protective covering of the seed. Lemma and palea generally adhere to the endosperm.

### Aleurone

A layer of protein surrounding the endosperm that secretes enzymes to break down starch reserves in the endosperm during germination.

Table i: Zadoks decimal growth scale for cereals.

GERMINATION		HEAD EMERGENCE	
00	Dry seed	50	1st spikelet of head just visible
01	Start of imbibition	53	1/4 of head emerged
03	Imbibition complete	55	1/2 of head emerged
05	Radicle emerged from seed	57	3/4 of head emerged
07	Coleoptile emerged	59	Emergence of head complete
09	Leaf just at coleoptile tip	ANTHESIS (FLOWERING)	
SEEDLING GROWTH		61	Beginning of anthesis
10	First leaf through coleoptile	65	Anthesis 50%
11	First leaf unfolded	69	Anthesis compete
12	2 leaves unfolded	MILK DEVELOPMENT	
14	4 leaves unfolded	71	Seed watery ripe
16	6 leaves unfolded	73	Early milk
18	8 leaves unfolded	75	Medium milk
TILLERING		77	Late milk
20	Main shoot only	DOUGH DEVELOPMENT	
21	Main shoot & 1 tiller	83	Early dough
22	Main shoot & 2 tillers	85	Soft dough
24	Main shoot & 4 tillers	87	Hard dough
26	Main shoot & 6 tillers	RIPENING	
28	Main shoot & 8 tillers	91	Seed hard (difficult to divide by thumbnail)
STEM ELONGATION		92	Seed hard (can no longer be dented by thumbnail)
30	Stem starts to elongate (head at 1 cm)	93	Seed loosening in daytime
31	1st node detectable	94	Overripe, straw dead & collapsing
32	2nd node detectable	95	Seed dormant
34	4th node detectable	96	Viable seed giving 50% germination
36	6th node detectable	97	Seed not dormant
37	Flag leaf just visible	98	Seed dormancy induced
39	Flag leaf/collar just visible		
BOOTING			
41	Flag leaf sheath extending		
43	Boot just visibly swollen		
45	Boot swollen		
47	Flag leaf sheath opening		
49	First awns visible		

Source: Based on Zadocks et al. (1974)



## Endosperm

Tissue that surrounds the embryo and provides energy for germination. The germinating seed relies on these reserves until it has developed a root system and sufficient leaf area for photosynthesis. The endosperm makes up the bulk of the grain and stores carbohydrate in the form of starch from which the fermentable sugars are formed during malting.



Figure v. Barley grain. Photo: Tim McNee

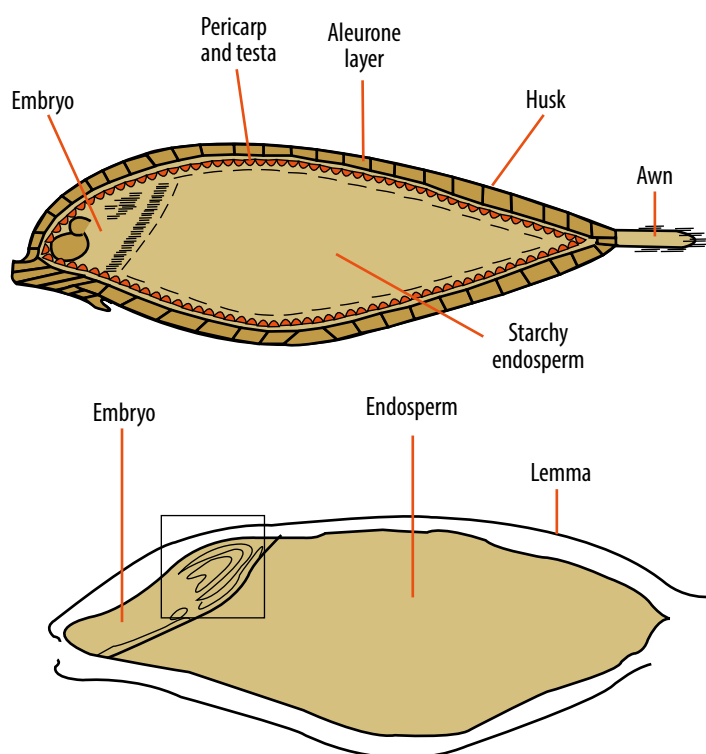


Figure vi. The basic composition of the barley grain. Source: Based on Kirby and Appleyard (1984)

## Embryo

Contains the main plant structures, so it holds all the elements of the growing plant. It is made up of the scutellum, plumule (shoot) and radicle (primary root). It is found at the point where the grain is attached to the spikelet.

## Scutellum

A shield-shaped structure that absorbs the soluble sugars from the breakdown of starch in the endosperm. It also secretes some of the enzymes involved in germination.

## Embryonic leaves (plumule)

The growing point of the seed that develops into the shoot bearing the first true leaves. At the growing point are the coleoptile, the three-leaf primordia (the young leaves recently formed by the apical meristem of the shoot) and the shoot apex.

## Radicle

Develops into the primary root and is the first structure to emerge after germination. The rootlet is protected by a root cap as it penetrates the soil.

## The barley plant

The main structures of the plant are the coleoptile, leaves, tillers, stem, roots and head.

## Coleoptile

The coleoptile is a protective sheath that encases the first leaf. It pushes through the soil to the surface.

## Leaves

The leaf consists of a sheath, which wraps around the newly emerging leaf, and a leaf blade. The leaf sheath contributes to stem strength. The leaf collar is the point where the leaf sheath joins the leaf blade. The leaf collar has two features, the ligule and the auricles. The ligule is a thin colourless membrane around the base of the collar. The auricles are large hairless projections that extend from the side of the leaf collar.

These features can be used to help identify grass species (see Figures vii and viii).

Leaves are produced in a set order, on alternate sides of the stem. A leaf is counted as emerged when the ligule is fully visible. The final leaf to grow before head emergence is the flag leaf.

## Tillers

Tillers are lateral branches or shoots that arise from buds in the axil of the leaves at the base of the main stem. Primary tillers are produced from the leaves of the main stem and can form their own, secondary tillers.

## Stem

The stem is made up of nodes and internodes. Nodes are where structures such as leaves, roots, tillers and spikelets join the stem. The internode is the tissue between adjacent nodes that elongates as the stem grows. The stem is wrapped in the sheaths of the surrounding leaves. This structure of stem and leaves gives strength to the shoot, helping to keep the plant upright.

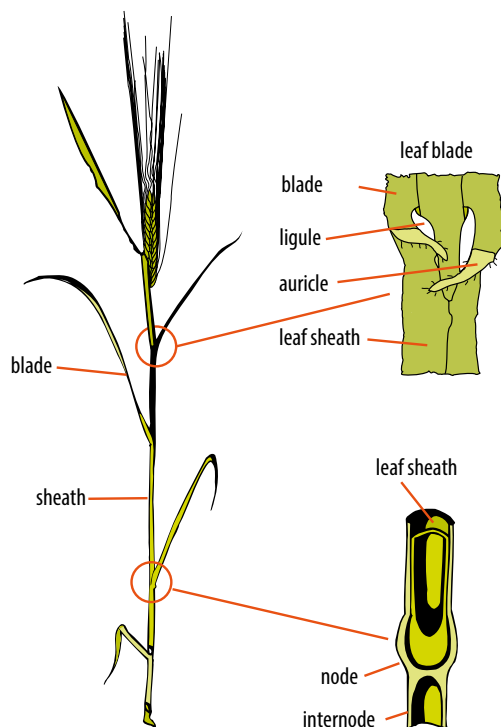


Figure vii. Structure of the barley leaf.  
Source: Based on Anderson and Garlinge (2000)

As the stem grows it changes function from providing support for leaves to storing carbohydrates and nutrients for grain-filling.

## Roots

Barley has primary and secondary root systems (Figure ix). The first roots to appear are the primary roots (also called seminal or seedling roots). At germination, the radicle breaks through the seed coat, followed by four or five lateral roots. These form the primary root system that supports the plant until the secondary roots (also called adventitious, nodal or crown roots) initiate from nodes within the crown.

## Head

There are two basic types of barley, determined by the number of rows of grain along the head. In two-row types the side spikelets are sterile, with only one fertile spikelet per side of the head. In six-row barley, all three spikelets per side of the head are fertile (Figure x). Three rows of grain grow from each node of the rachis on alternate sides of the head. Two-

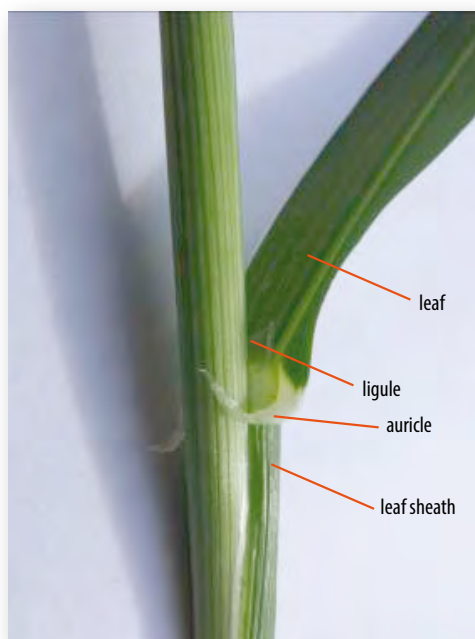


Figure viii. Leaf collar showing the ligule and auricles.  
Photo: Tim McNee

row barley varieties are more commonly grown commercially in NSW.

The head of the barley plant has a rachis (stem) made up of nodes and short, flattened internodes. At the nodes are the floral structures, called spikelets, that hold

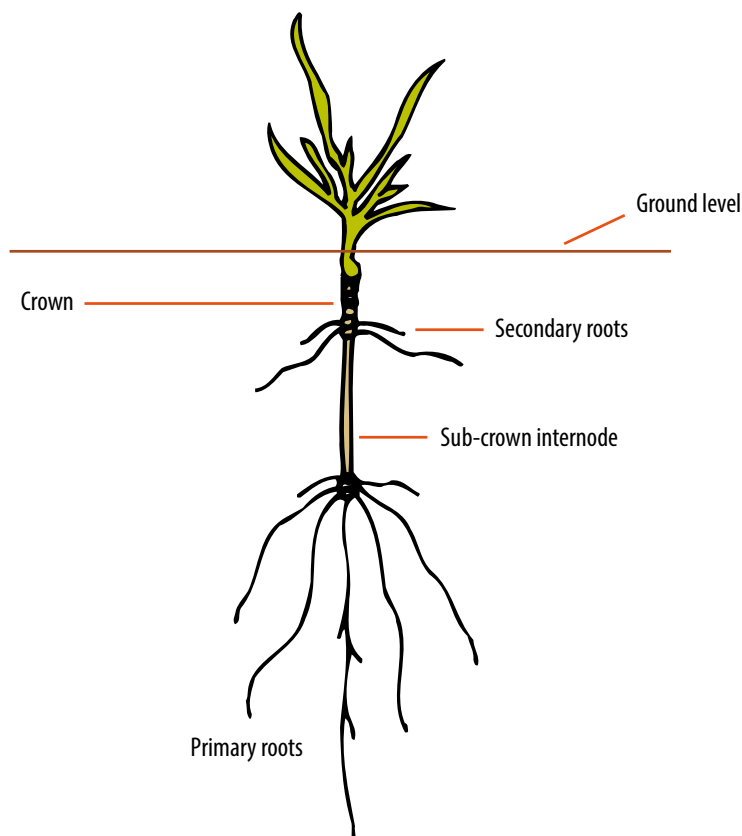


Figure ix. The barley plant, showing the primary and secondary root systems  
Source: Anderson and Garlinge (2000)

up to six florets containing the flower of the barley plant, where the grain is formed. Figure xi shows a mature barley head.

Each floret is enclosed within two protective bracts called the lemma and palea. These structures wrap around the carpel. The carpel contains the ovary with the feathery stigmas, three stamens holding the anthers (pollen sacs), and the ovule. Once fertilised, the ovule forms the grain. Figure xii shows a dissected barley spikelet.

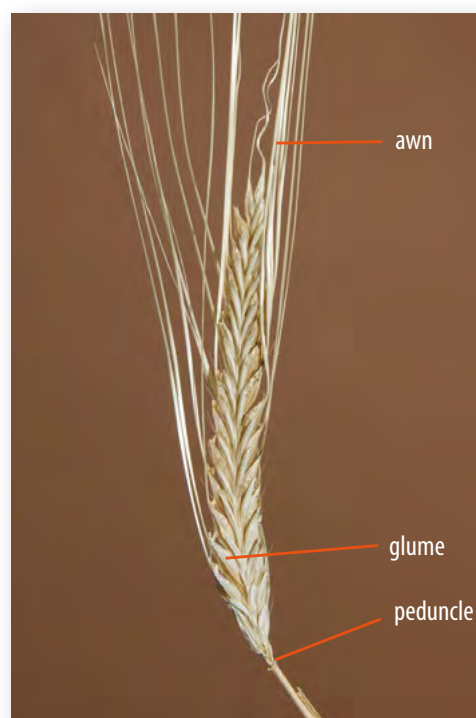


Figure xi. Mature barley head. Photo: Lowan Turton

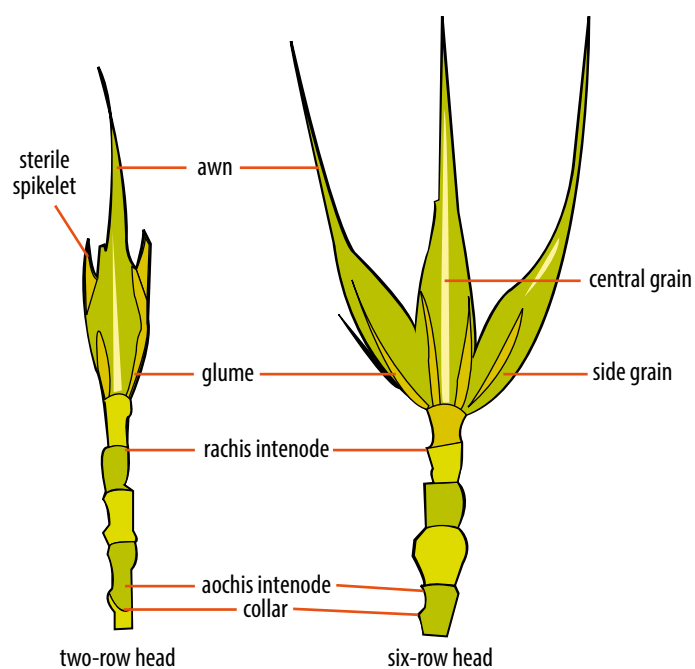


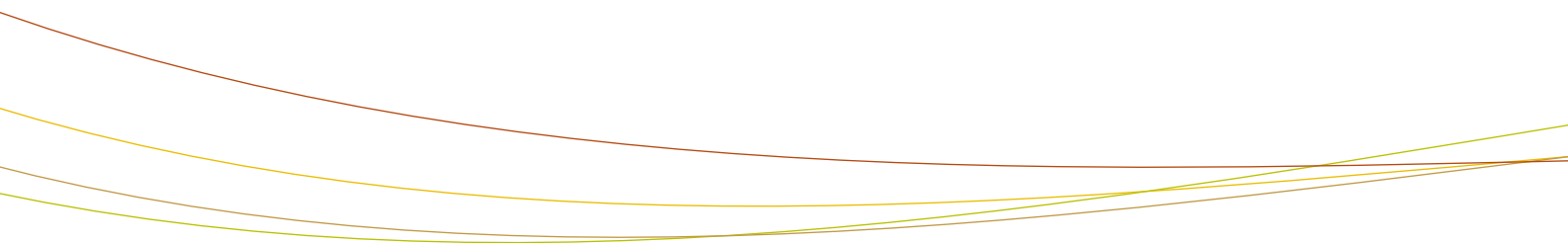
Figure x. Comparison of spikelets in two- and six-row heads of barley.  
Source: Fitzsimmons and Wrigley (1984)



Figure xii. Dissected barley spikelet, showing the enclosed anthers. Photo: Tim McNee

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# 1. Germination, emergence and establishment

by Phillip Bowden and Neil Fettell

## Chapter Snapshot

Germination (Z00) – 12

*Phase 1 Water absorption (Z01), Phase 2 Activation (Z03), Phase 3 Visible germination (Z05–Z07), Coleoptile formation*

Emergence (Z07) – 13

Establishment (Z10) – 13

Factors affecting germination, emergence and establishment – 13

*Oxygen, Dormancy, Moisture, Temperature, Seed quality and 1000-grain weight, Nutrition, Seed treatment, Sowing, Plant population*

References and further reading – 20

In the paddock – 21

*1000-grain weight, Graded versus ungraded seed, Treated and untreated seed, Calculating the germination percentage, Calculating sowing rates, Sowing implements and seed placement, Coleoptile length and sowing depth, Plant population*

## Introduction

*Under the right conditions, a viable barley seed germinates. Chapter 1 is about the processes in which the first shoot emerges from the ground and root growth begins. This chapter covers germination, emergence and establishment of the barley plant life cycle.*

## Learning Outcomes

At the end of this chapter you will be able to:

- describe the germination process and the roles of moisture, temperature and oxygen
- explain plant emergence and establishment and the roles of moisture and temperature
- understand the factors that influence coleoptile length
- recognise the qualities to look for when selecting seed
- conduct a germination and 1000-grain weight test
- calculate a sowing rate to target a plant population.

## Germination (Z00)

### Radicle

Part of the seed embryo that grows into the primary root.

Germination begins when the seed absorbs water and ends with the appearance of the **radicle**. Germination has three phases:

- water absorption (imbibition)
- activation
- visible germination.

### Phase 1 Water absorption (Z01)

Phase 1 starts when the seed begins to absorb moisture (see Figure 1–1). As a general rule, a barley seed needs to reach a moisture content of around 35% to 45% of its dry weight to begin germination. Water vapour can begin the germination process as rapidly as liquid. Barley seeds begin to germinate at a relative humidity of 97.7%. Soil that is so dry that roots can't extract water still has a relative humidity of 99%, which is much higher than that of a dry seed. As a result of this, even in seemingly dry conditions, there can be enough moisture for the seed to absorb water and begin Phase 1. The process will take longer than when soil is at field capacity, but germination will have been initiated.

### Phase 2 Activation (Z03)

Once the embryo has swollen it produces hormones that stimulate enzyme activity. The enzymes break down starch and

protein stored in the seed to sugars and amino acids, providing energy to the growing embryo. If the seed dries out before the embryo starts to grow it will remain viable, but still dormant.

Phase 2 continues until the rupture of the seed coat, the first visible sign of germination.

### Phase 3 Visible germination (Z05–Z07)

In Phase 3 the embryo starts to visibly grow. The radicle emerges, followed soon after by other primary roots and the coleoptile (Figure 1–2). The enzymes produced in Phase 2 mobilise sugars and amino acids stored in the seed and enable their transfer to the growing embryo.

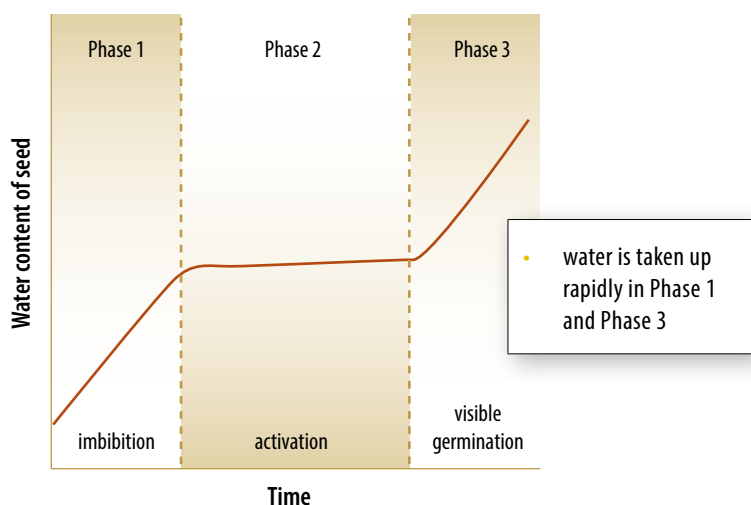


Figure 1–1: Pattern of water uptake by wheat seeds in a moist environment.  
Source: Passioura (2005)

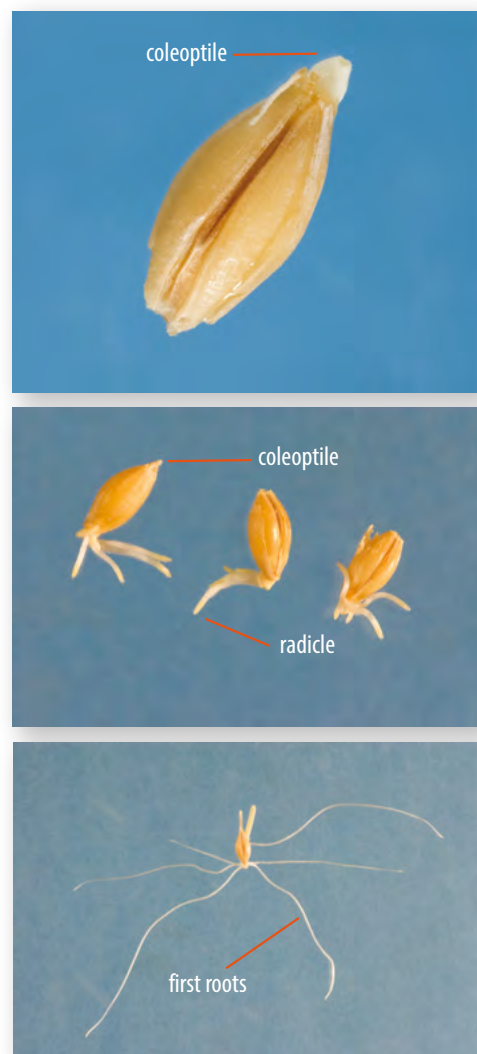


Figure 1–2: Germinating barley seeds. Photos show the radicle, coleoptile and first roots emerging. Photo: Lowan Turton

## Coleoptile formation

The coleoptile is a protective cylindrical sheath-like structure that surrounds the first leaf. It is well developed in the embryo, forming a thimble-shaped structure covering the seedling leaf and the shoot. Once the coleoptile emerges from the seed it increases in length until it reaches the soil surface.

The fully elongated coleoptile is a tubular structure ranging from 50 to 80 mm long and about 2 mm in diameter (Figure 1–3). It is white, except for two strands of tissue that contain chlorophyll. The end of the coleoptile is bullet shaped and is closed except for a small pore, 0.25 mm long, a short distance behind the tip.

When the coleoptile senses light it stops growing and the first true leaf pushes through the pore at the tip. Up to this point the plant is living on energy (carbohydrate) reserves within the seed.



Figure 1–3. The emerging coleoptile. Photo: Lowan Turton

## Emergence (Z07)

As the first primary roots appear the coleoptile bursts through the seed coat and begins pushing towards the surface. Emergence occurs when the coleoptile is visible above the soil surface.

Extension of the coleoptile is directly related to soil temperature. Soils that are too cold or too hot shorten the coleoptile length. Coleoptiles are longest when soil temperatures are between 10°C and 15°C. This results in variation in emergence and establishment times for different sowing dates and for different regions. Barley cultivars differ in coleoptile length, but this characteristic is not closely linked to plant height or to dwarfing genes.

Some tall varieties (e.g. Buloke) have short coleoptiles, whereas some short varieties (e.g. Baudin) have relatively long coleoptiles.

Sowing seeds deeper than the coleoptile length will result in the coleoptile not reaching the surface, making plant emergence unlikely. Deeply sown seeds also lack early vigour, and tillering can be delayed.

## Establishment (Z10)

The plant is established once it has roots and a shoot. It no longer relies on reserves in the seed once it produces its own energy from photosynthesis.

## Factors affecting germination, emergence and establishment

### Oxygen

Oxygen is essential to the germination process. Seeds absorb oxygen rapidly during germination and will die without sufficient oxygen. Germination is slowed when the soil oxygen concentration is below 20%. During germination, water softens the seed coat to make it permeable to oxygen, so dry seeds absorb almost no oxygen.

Seeds planted in waterlogged soils will imbibe and swell but cannot germinate because of a lack of oxygen. It is commonly thought that in very wet conditions seeds ‘burst’, but what actually happens is they run out of oxygen and die.

### Dormancy

In a barley seed, germination begins after a very short period of dormancy. Some level of seed dormancy is necessary to help prevent ripe grain from germinating in the head before harvest. However, excessive dormancy can be a problem in malting barley, forcing maltsters to store the grain for an extended period after harvest before it can be successfully

malted. Australian varieties generally have low dormancy, some such as Hamelin and Flagship being particularly low.

In Australian barley at least two genes influence the level of dormancy. One gene is in the embryo of the seed and needs to be present for any level of seed dormancy to develop. This gene makes the seed sensitive to the plant hormone abscisic acid, which prevents germination at the time of crop maturity.

The second gene is in the seed coat and, in combination with the embryo gene, produces a more robust and stable dormancy. Because of summer rainfall this level of dormancy is essential in cultivars targeted for Queensland and northern NSW, and it is desirable in southern Australia.

## Moisture

Soil moisture influences the rate of germination. Germination is rapid if the soil is moist. When the soil dries to near the wilting point, the speed of germination slows. When the soil reaches the permanent **wilting point**, germination will take 10 days at 7°C instead of taking 5 days at 7°C when there is adequate moisture.

A germinating seed has the ability to stop and start the process in response to the availability of moisture. Therefore, seeds that have taken up water and entered Phase 2, but have not reached Phase 3, remain viable if the soil dries out. When the next fall of rain comes, the seed resumes germinating, taking up water and moving quickly through Phase 2.

This ability to start and stop the germination process (in response to conditions) before the roots and coleoptile have emerged is an important consideration when dry sowing. If the seed bed dries out before the coleoptile has emerged, the crop needs to be monitored to determine whether it will emerge, so that the decision on whether to re-sow can be made.

The presence of hard-setting or crusting soils that dry out after sowing may result in poor emergence. The hard soil makes it difficult for the coleoptile to push through to the surface, particularly in varieties with short coleoptiles.

In some crusting soils, gypsum and/or lime may improve soil structure and help seedling emergence. The presence of stubble lowers evaporation rates, reduces the impact of raindrops on the soil surface and helps prevent soil crusts from forming. Stubble retention also encourages biological activity and increases the amount of organic matter, which improves the stability of the soil by binding the soil particles together.

## Temperature

### *Effect on germination*

Germination rate depends on temperature. The ideal temperature for barley germination is between 12°C and 25°C, but germination will occur between 4°C and 37°C.

The speed of germination is driven by accumulated temperature, or 'degree-days'. A degree-day is the average of the daily maximum and minimum temperature on a particular day compared with a base temperature (for barley, 0°C during vegetative growth and 3°C in the reproductive phase). Barley requires 35 degree-days for visible germination to occur. At an average temperature of 7°C it takes 5 days before visible germination (Table 1–1). At 10°C it takes 3.5 days. Other examples are presented in Table 1–2.

### *Effect on emergence and establishment*

High temperatures during establishment cause seedling mortality, reducing the number of plants that establish. In hot environments, the maximum temperature in the surface soil can be 10°C to 15°C higher than the maximum air temperature, especially with a dry, bare soil surface and high radiation intensity. In these conditions, soil temperature can reach 40°C to 45°C, which seriously inhibits seedling survival and emergence. Brief exposure to extreme soil temperatures can also restrict root growth and tiller initiation.

The overall impact of temperature during emergence and establishment varies between varieties. Table 1–3 shows the average number of plants established in one trial with increasing soil temperatures. The equivalent to 100 kg seed/ha was planted at a depth of 30 to 40 mm. Soil temperature was measured in the field at a depth of 50 mm.

### Wilting point

(or crop lower limit) is the point at which roots can't extract water.

Table 1–1: Degree-days required for germination and emergence.

NO. OF DEGREE-DAYS REQUIRED	
Root just visible	27
Coleoptile visible	35
Emergence (40 mm)	130
Each leaf	100

Source: Passioura (2005).

Table 1–2: Examples of how different temperatures affect germination.

TEMPERATURE	NO. OF DAYS TO GERMINATION
3.5°C	10
5°C	7
7°C	5
10°C	3.5

Source: Passioura (2005).

Table 1–3: Number of plants established at various soil temperatures.

MEAN MAX SOIL TEMP (°C)	PLANTS ESTABLISHED (plants/m <sup>2</sup> )
20.2°C	315
33.2°C	256
42.2°C	89

Note: the difference between 20.2°C and 33.2°C is statistically significant. Source: Acevedo, Silva & Silva (2002).

## Seed quality and 1000-grain weight

Early seedling growth relies on stored energy reserves in the seed. Good seedling establishment is more likely if seed is undamaged by insects or harvesting, is stored at suitable temperatures and moisture conditions, and comes from a plant that had adequate nutrition during its growth and grain-filling period. Seed size is also important. The larger the seed, the larger the endosperm and starch reserves. So although seed size does not alter germination, bigger seeds have faster seedling growth, higher numbers of fertile tillers per plant, and potentially higher grain yields. Research by Neil Fettell at Condobolin in 2008 showed that whereas small seed (25.64 g per 1000 seeds) had emergence equal to 90% of that of large seeds (41.31 g per 1000 seeds) when sown at 44 mm, this dropped to 67% when sown at 87 mm and 53% when sown deep (112 mm).

Seed size is usually measured by weighing 1000 grains. This is known as the 1000-grain weight. The 1000-grain weights vary among varieties and from season to season. Thus sowing rate needs to vary according to the 1000-grain weight for each variety, and each season, in order to achieve desired plant densities. Seed grading is an effective way to separate good quality seed of uniform size from small or damaged seeds and other impurities.

## Seed storage

A seed is a living organism that releases moisture as it respire. The aim of seed storage is to preserve the viability of the seed for future sowing. Four issues need to be considered: temperature, moisture, aeration and pests. The following are required:

- Temperature below 15°C. High temperatures can quickly damage seed germination and quality.
- Moisture below 12% (see Figure 1–4). Temperature changes cause air movements inside the silo that carry moisture to the coolest parts of the silo. Moisture is carried upwards by convection currents in the air created by the temperature difference between the warm seed in the centre of the silo and the cool silo walls, or vice versa. Moisture carried into the silo headspace may condense and fall back as free water, causing a ring of seed to germinate against the silo wall.
- Aeration slows the rate of deterioration of seed if the moisture content is kept between 12.5% and 14%. Aeration markedly reduces grain temperature and evens out temperature differences that cause moisture movement.
- Pest management. Temperature below 15°C stops all major grain insect pests from breeding, slowing down their activity and resulting in less damage.



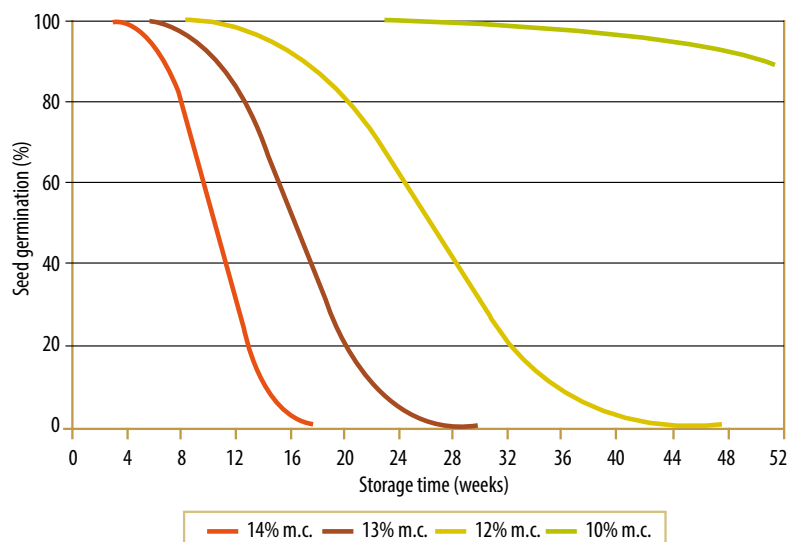


Figure 1–4. Survival of barley seed when stored at 35 °C and at a range of moisture contents. m.c. = moisture content. Source: Caddick (undated)

## Nutrition

Adequate nutrition is essential for good plant growth and development, yield and grain quality. Nutritional requirements vary depending on potential yield and soil fertility status. Soil tests or nutrient budgeting are a useful way of measuring soil fertility and calculating fertiliser requirements before sowing.

Historically, rates of fertiliser application to barley crops have been low. Barley was perceived to perform well on poor soils and in low-fertility situations. This is not true. In fertile soils barley will yield comparably to wheat, without necessarily producing a protein level above that acceptable for malting specifications.

## Nitrogen

Nitrogen is essential to plant growth and is commonly applied at moderate to high levels before or at sowing. When N is applied at high rates, products rich in nitrogen are commonly used (e.g. anhydrous ammonia or urea). When anhydrous ammonia is applied, the soil needs to be moist so that the product is sealed within the soil. Nitrogen can be leached from light soil if sowing is delayed by heavy rains or continuous wet weather.

Excessive nitrogen fertiliser application close to the seed can lead to toxicity problems. Under good moisture conditions, seed can tolerate a maximum

of about 25 kg of N/ha without seedling mortality. This amount is based on an 18 cm row spacing and fertiliser banded with the seed.

Deep banding is one method of applying nitrogen fertiliser at sowing without causing seedling losses. This requires the use of seeding systems that can separate seed and fertiliser by more than 25 mm. Pre-drilling of nitrogen is another option, where urea is pre-drilled before sowing. Alternatively, nitrogen fertiliser can be broadcast and incorporated at sowing.

The markets for malting barley demand moderate protein levels, and feed barley growing does not pay premiums for protein. Therefore, it is good practice to apply nitrogen fertilisers for vegetative growth early to give a higher yield potential, rather than having reserves of nitrogen at grain-filling that the plant will put into grain protein.

There is no reason to be wary of high-fertility paddocks or the use of nitrogen fertiliser to increase the yield potential of barley. After moderate additions of nitrogen the protein percentage can remain relatively constant, whereas the yield can increase dramatically. High nitrogen availability or the use of high levels of nitrogen fertiliser can lead to an increase in protein percentage. The major determinant of protein level is the seasonal conditions during grain fill. A hot, dry finish produces smaller grain of higher protein level than is produced with a cool, moist finish. Malting grade can be difficult to achieve in drier western areas, although much of the malting barley does come from there.

Nitrogen rates will vary depending on whether you are trying to meet malt specifications, use the crop for grazing, or maximise the yield of a feed variety.

## Phosphorus

Phosphorus is essential for seed germination and early root development and for increasing seedling vigour and establishment. Large amounts are taken up during early growth. Phosphorus deficiency at this early stage of growth significantly reduces yield potential, particularly by reducing tiller production and survival.

Many of the soils in NSW have low levels of phosphorus, and in some areas phosphorus is the limiting nutrient.

Low phosphorus levels can actually increase the protein content of the grain, making it unsuitable for malt classification.

Unlike nitrogen, phosphorus is immobile in the soil, making placement near the seed critical. Therefore, regardless of the soil test results, some phosphorus needs to be applied with the seed at sowing. Phosphorus rates should be similar to those in wheat.

One method of estimating phosphorus requirements is to allow for phosphorus at 5 kg/t of target yield. For example, a 3 t/ha barley crop requires 15 kg/ha of phosphorus. Phosphorus application rates should be increased by 20% to compensate for slow root growth and P uptake and moisture uptake in dry years. Delays in the uptake of P to critical levels can delay maturity, which in turn can increase grain screenings.

### Seed treatment

Seed treatments are applied to control diseases such as smuts, bunts and foliar diseases and to control insects. When applying seed treatments always read the chemical label and calibrate the applicator. It is critical that seed treatments are applied evenly and at the right rate. Seed treatments are best used in conjunction with other disease management options, such as crop and paddock rotation, the use of clean seed, and the planting of resistant varieties.

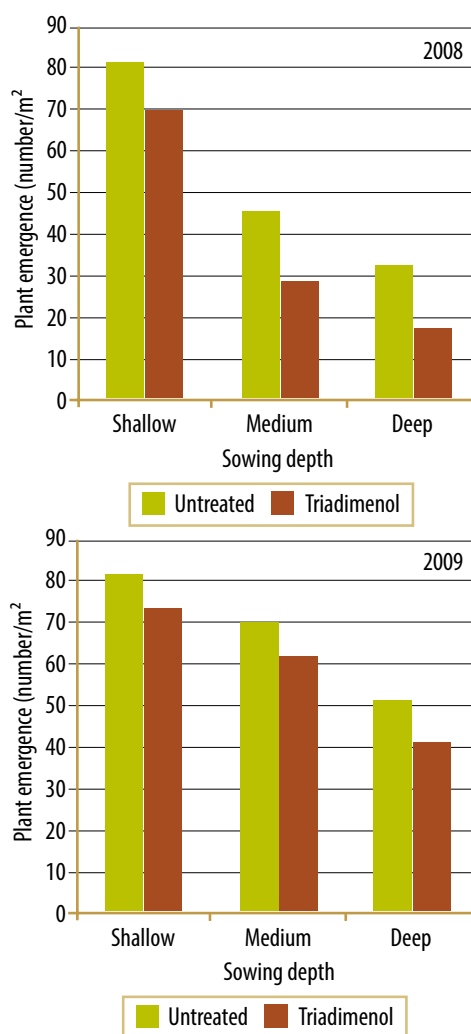
There are some risks associated with the use of seed treatments. Research shows that some seed treatments can delay emergence by:

- slowing the rate of germination
- shortening the length of the coleoptile, the first leaf and the sub-crown internode.

Any delay in emergence increases exposure to pre-emergent attack by pests and pathogens or to soil crusting, which may lead to a failure to emerge. The risk of emergence failure is increased when seed is sown too deeply or into a poor

seed bed, especially in varieties with shorter coleoptiles.

Some seed treatments contain triazole fungicides (triadimenol and triadimefon). These seed treatments can reduce coleoptile length, and the degree of reduction increases as the rate of application increases. Recent research in barley has shown that the highest registered rate of triadimenol can reduce emergence in barley, and that the reductions are greatest in varieties with short coleoptiles when sown at depths greater than 50 mm (Figure 1–5). The results emphasise the need to sow varieties that have short coleoptiles at shallow depths and to take care with seed grading and the use of seed dressings.



- Triadimenol reduced emergence in 2009, but the effect was much smaller than in 2008.
- The effect was greater with deeper sowing.
- Averaged over 12 varieties, triadimenol reduced emergence by 11% at the two shallower depths and 19% with deep sowing.

Figure 1–5. Plant emergence from untreated and triadimenol-treated seed, averaged over 12 varieties in 2008 and 2009. Source: Fettel and McMullen (2010)

## Sowing

### Seedbed

Barley seed needs good soil contact for germination. This was traditionally achieved by producing a fine seedbed by multiple cultivations. Good seed–soil contact can now be achieved by the use of press wheels or rollers. Soil type and soil moisture influence the choice of covering device.

Between 70% and 90% of seeds sown produce a plant. Inappropriate sowing depth, disease, crusting, moisture deficiency and other stresses all reduce the numbers of plants that become established. Field establishment rates can be 60% or lower if seedbed conditions are unfavourable.

Seedbed preparation is also important to emergence. A cloddy seed bed can reduce emergence rates, as the clods reduce seed–soil contact, stop some seedlings reaching the surface, and allow light to penetrate below the soil surface. The coleoptile senses the light and stops growing, and a leaf is produced while still below the surface. Cloddy soils also dry out more quickly.

## Depth

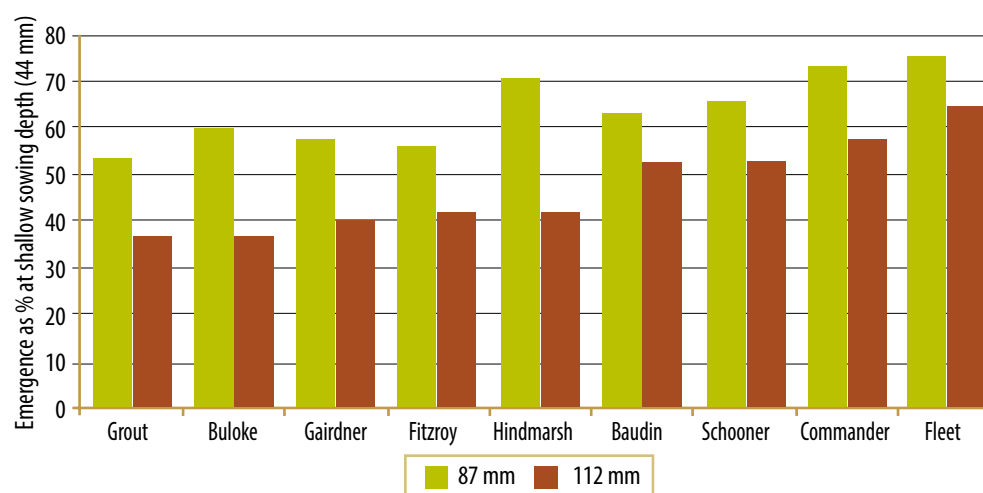
Sowing depth is the key management factor for uniform rapid emergence and establishment. The ideal depth to sow barley is generally 20 to 30 mm, depending on the availability of moisture and the variety. Depth is particularly important in varieties with short coleoptiles.

Sowing depth influences the rate of emergence and the percentage of seedlings that emerge (see Figure 1–6). Deeper seed placement slows emergence; this is equivalent to sowing later. Seedlings emerging from greater depth are also weaker and tiller poorly.

Crop emergence is reduced with deeper sowing. The coleoptile may stop growing before it reaches the soil surface, and the first leaf then emerges from the coleoptile while it is still below the soil surface. As the leaf is not adapted to pushing through soil, it usually buckles and crumples, failing to emerge and eventually dying.

## Plant population

Plant population is influenced by seeding rate, row spacing and emergence percentage. Emergence percentage is calculated as the number of seedlings



- Plant emergence decreased with deeper sowing.
- When plants were sown at 87 mm, emergence was 50% to 80% of that with sowing at 44 mm.
- When plants were sown at 112 mm, emergence was 35% to 60% of that with sowing at 44 mm.
- The effect of sowing depth differed among varieties.

Figure 1–6. Plant emergence at Condobolin 2008 for medium (87 mm) and deep (112 mm) sowing, expressed as a percentage of the emergence from shallow (44 mm) sowing. Source: Fettel and McMullen (2010)

(counted at the second leaf stage) divided by the number of seeds sown per square metre. Target plant populations vary with yield potential, seasonal conditions and sowing date. Current recommendations for NSW (see Industry & Investment NSW's *Winter crop variety sowing guide*) range from 80 to 120 plants/m<sup>2</sup>. When populations fall below 50 plants/m<sup>2</sup>, yield is affected. At less than 30 plants/m<sup>2</sup> the paddock should be resown, unless it is undersown with a legume.

Barley is able to compensate for lower than ideal plant populations, to some degree, by increasing tiller numbers. However, targeting plant population at sowing makes the most efficient use of water and nutrients. To reach a target plant population for the environment and seasonal conditions, adjust sowing rates to allow for:

- soil moisture
- sowing date: higher rates with later sowings (tiller capacity is more limited with later sowings)

- seed germination percentage
- seed size
- seedbed conditions
- tillage (e.g. increase sowing rate with no till)
- double cropping
- soil fertility (increase sowing rate with increasing yield potential)
- soil type (e.g. crusting)
- field losses (e.g. increase sowing rate if there is a problem with insects).

Appropriate seeding rates are important in barley for both grain yield and grain quality. Typical responses of five current varieties are shown in Figure 1–7, from a trial at Rankins Springs in 2005. Yield increased with seeding rate up to about 120 plants/m<sup>2</sup> in most varieties, whereas kernel weight decreased with each increase in plant density for all varieties. Retention also decreased with increases in

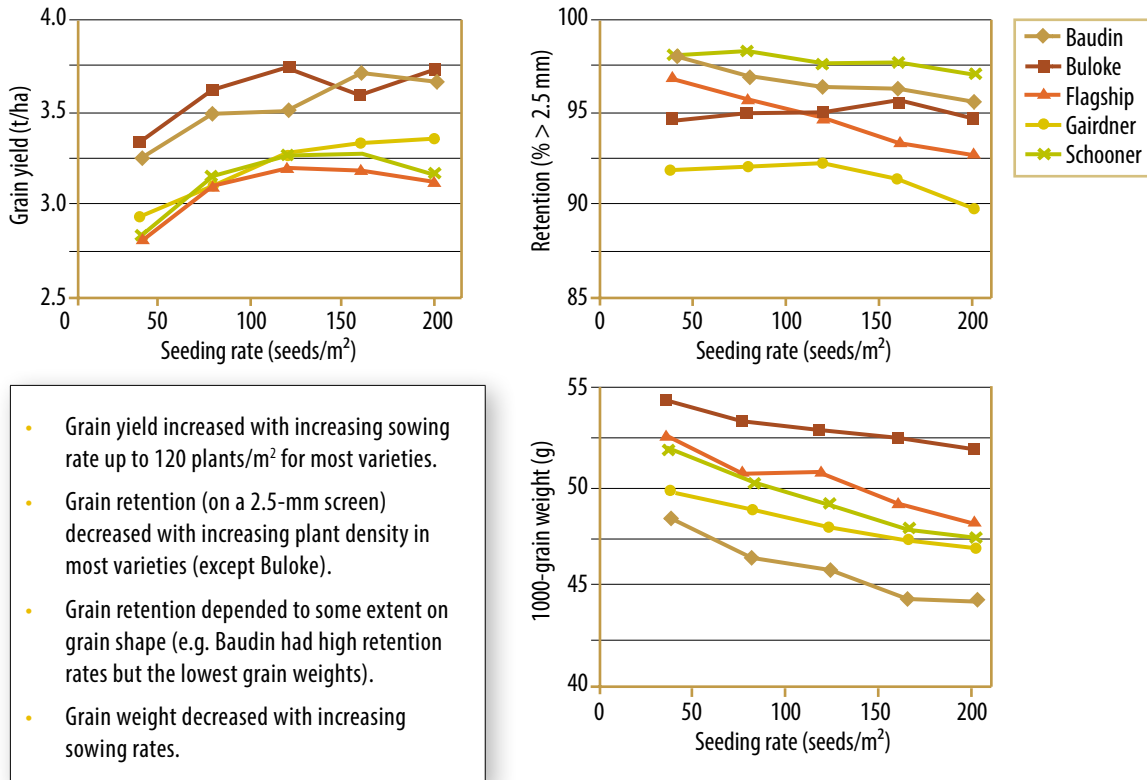


Figure 1–7. Grain yield, retention and 1000-grain weight responses to seeding rate in five varieties at Rankins Springs in 2005. Source: Fettell (2007)

plant density in all varieties except Buloke, although the decline was only minor in Schooner. The effect of grain shape was evident. Buloke had the heaviest grains but was intermediate for retention, whereas Baudin had high retention values and the lowest kernel weights. High seeding rates should be avoided in Gairdner.

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## IN THE Paddock

The following are some examples of what can be done in the paddock to demonstrate the stages of growth and development that have just been discussed.

### 1000-grain weight

*Aim: to determine the 1000-grain weight of a seed lot.*

1. Count out 200 seeds from each seed lot to be planted.
2. Discard seeds that will be removed by cleaning/grading.
3. Weigh 200 seeds on scales accurate to 0.1 g.
4. Multiply the result by 5 to calculate the 1000-grain weight.
5. Repeat 5 times.

1000-GRAIN WEIGHT (g)		
COUNT	SEED LOT 1	SEED LOT 2
1		
2		
3		
4		
5		
Average		

### Graded versus ungraded seed

*Aim: to compare a sample of a graded seed lot with one off the header.*

1. Weigh out a small amount (e.g. 100 g) from both the graded seed lot and off the header.
2. Separate the plump, whole grains from the cracked and small grain, and the foreign bodies from the seed off the header.
3. Weigh each portion and compare the results.

#### **Other suggestions:**

Look at partial germination and seed that has been shot and sprung.

### Treated and untreated seed

*Aim: to use coleoptile length measurements to compare treated and untreated seed.*

1. Conduct this activity at emergence in paddocks that have been treated with different seed treatments, and in paddocks where untreated seed was sown.
2. Record the coleoptile lengths of 10 seedlings from each paddock and compare results.
3. Compare emergence dates in paddocks where treated and untreated seed was sown.

## IN THE Paddock

### Calculating the germination percentage

*Aim: calculate the germination percentage of a seed lot.*

1. Collect 50 seeds from each lot to be planted.
2. Lay four sheets of paper towel on top of each other and moisten, don't drench.
3. Place 50 seeds 10 mm apart on the paper towels.
4. Roll up, sandwiching the seeds between the moist paper towels.
5. Soak a hand towel in water and ring out, then wrap it around the rolled-up paper towel and loosely secure with rubber bands.
6. Place in a plastic bag, seal and place in a warm spot, such as the kitchen bench near a window, and leave for 5 to 7 days.
7. Unwrap and count the number of seeds that have not germinated.

Do your calculation as follows:

Germination % = [(number of seeds tested – number of seeds that didn't germinate) ÷ 50] × 100.

Repeat five times.

GERMINATION PERCENTAGE		
COUNT	SEED LOT 1	SEED LOT 2
1		
2		
3		
4		
5		
Average		

### Calculating sowing rates

*Aim: calculate a sowing rate based on a target plant density.*

1. Decide on a target plant density  
(refer Industry & Investment NSW's *Winter crop variety sowing guide*).
2. Calculate the 1000-grain weight using the following formula to calculate sowing rates:

$$\text{Sowing rate kg/ha} = \frac{(\text{target density} \times 1000\text{-grain weight in grams} \div 100)}{(\text{establishment \%} \times \text{germination \%})}$$

COUNT	EXAMPLE 1	EXAMPLE 2	Paddock 1	Paddock 2
Target density	140	140		
1000-grain weight (g)	35	42		
Establishment	80% = 0.8	80% = 0.8	80% = 0.8	80% = 0.8
Germination	90% = 0.9	90% = 0.9		
Sowing rate	68	82		

## IN THE Paddock

### Sowing implements and seed placement

*Aim: to use coleoptile length measurements to compare the sowing depths of different tillage implements.*

1. Conduct the above activity in paddocks that have been sown with different types of planters or in different soil types.
2. Discuss soil throw in zero till and implications for emergence.
3. Observe and discuss the impact of deep furrows on seed placement and emergence.

### Coleoptile length and sowing depth

*Aim: to measure coleoptile length and sowing depth. Plants need to be assessed at the one- to two-leaf stage.*

1. Carefully dig up 10 plants along a row, including the seed and roots, in two paddocks.
2. Measure the depth from the seed to the soil surface (where the coleoptile ends and the green stem begins.)
3. Record the coleoptile lengths of the 10 plants from each paddock in the table below and calculate the average sowing depth.

COLEOPTILE LENGTH / SOWING DEPTH (cm)		
COUNT	Paddock 1	Paddock 2
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average		

### Plant population

*Aim: determine the plant population in a paddock.*

1. Count the plants along 1 m of row at 10 locations within the paddock.
2. Add the 10 counts together and divide by 10 to give the average number of plants/m of row.
3. Multiply the plant counts by the row spacing factor to convert plants/m row to plants/m<sup>2</sup>.
 

17.5 cm = 5.71	20 cm = 5.00	33 cm = 3.03
22.5 cm = 4.44	25 cm = 4.00	36 cm = 2.77
27.5 cm = 3.36	30 cm = 3.33	40 cm = 2.50

## IN THE Paddock

4. Repeat in a different paddock and record the results for both.

PLANT POPULATION		
COUNT	Paddock 1	Paddock 2
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Total		
Average per m row		
Plants/ m <sup>2</sup>		

5. Divide the number of seeds sown per square metre by the number of plants per square metre.  
This will give the establishment percentage.

# 2. Vegetative growth and plant development

by Neil Fettell and Nathan Border

## Chapter Snapshot

### Vegetative growth (Z10–Z31) – 26

*Root growth, Leaf growth, Tiller growth (Z23–Z29)*

### Factors affecting vegetative growth – 31

*Photosynthesis and respiration, Transpiration, Leaf area, Moisture, Nutrition, Leaf and root disease, Grazing*

### Factors affecting plant development – 35

*Vernalisation, Photoperiod, Basic vegetative period, Thermal time, Sowing time*

### References and further reading – 38

### In the paddock – 39

*Examining the root system, Assessing plant growth stage, Tiller counts, Dry matter assessment, Monitoring for pests, diseases and injury, Thermal time*

## Introduction

*Once the barley plant is established, it begins vegetative growth. Its root system continues to develop, leaves are initiated and tillering begins.*

*Chapter 2 explains vegetative growth and the factors that affect the growth and development of the plant.*

## Learning Outcomes

At the end of this chapter, you will be able to:

- identify the difference between growth and development
- describe how the root system grows
- understand the effect of vernalisation, photoperiod and thermal time on development in different varieties
- explain photosynthesis, respiration and transpiration
- understand how dry matter or biomass is accumulated
- describe the role of plant nutrition during vegetative growth
- locate the main stem and tillers of a barley plant
- assess the dry matter or biomass of a crop.



## Vegetative growth (Z10–Z31)

During the vegetative growth phase the roots, leaves and tillers develop and the plant begins storing nutrients for the rest of the growth cycle. This is a period of high nutrient uptake, and its progression is influenced by moisture and temperature levels.

**Growth** is the increase in the size and number of leaves and stems that produces a quantitative change in biomass. It is time based and is facilitated by photosynthesis, so it is directly related to water use and light interception.

**Development** is the process of the plant moving from one growth stage to another. The rate and timing of plant development are determined by variety, photoperiod and temperature.

### Root growth

The function of the root system is to absorb nutrients and water for plant growth. Healthy roots, unrestricted by soil constraints or disease, are essential to maximise yield. Roots also synthesise growth regulators or plant hormones.

Barley has a fibrous root system consisting of two parts, the primary and secondary roots (Figure 2–1). These have different functions and stages of development.

### Primary root system (Z12)

The primary (seminal or seedling) roots are the first to appear after germination. Between five and seven roots grow and branch as they extend deep into the soil. These roots form the deepest root system and, given adequate moisture and soil structure, they can grow to about 2 m in depth. However, under most NSW conditions they rarely exceed 1.5 m, and they can extract soil moisture to this depth.

### Secondary root system (Z13)

The secondary (adventitious) root system develops from the crown of the plant and is closely linked to tiller development. Dry conditions at tillering can inhibit secondary root development, causing the plant to rely solely on primary roots to produce some grain. The nodal roots grow horizontally for a while, before growing downwards and branching; this means that the layers of soil close to the surface are dominated by nodal roots.

Root growth continues into grain fill, and then the roots start to die off. The structure of the root system can be genetically influenced, as is highlighted by variations between varieties of different origins.

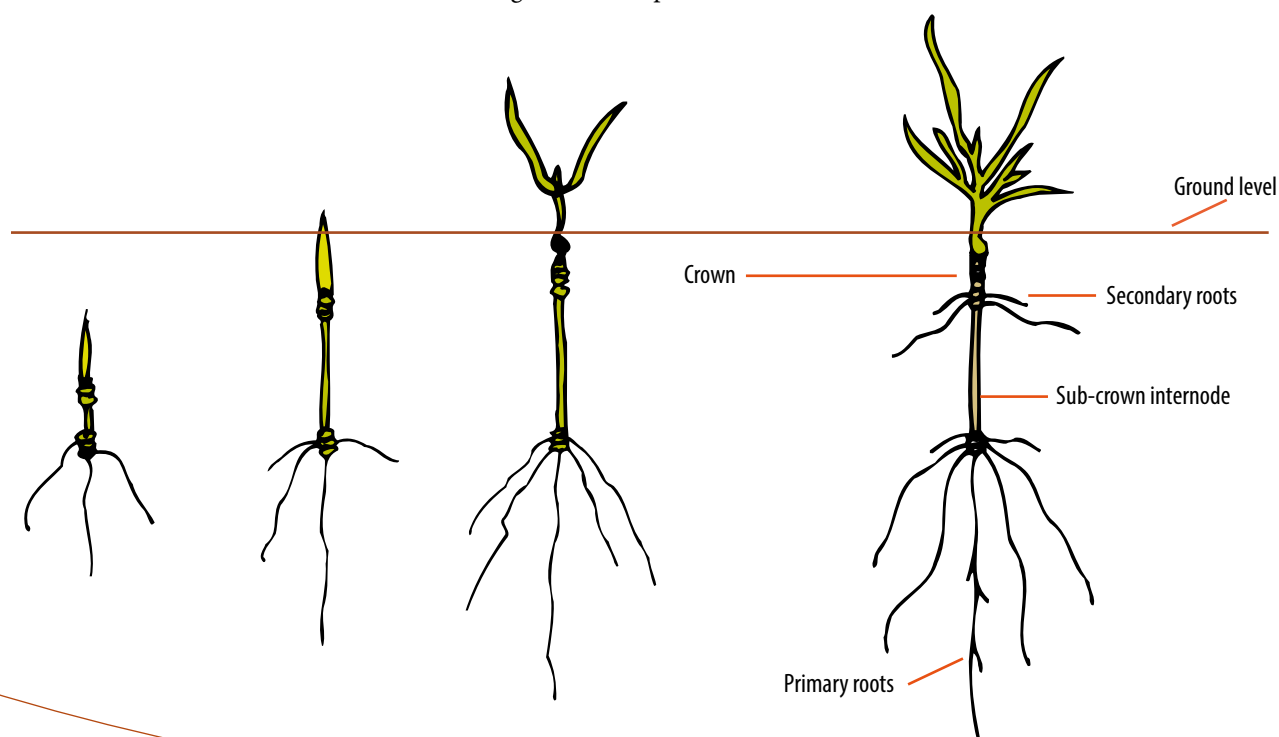


Figure 2–1. Growth of the primary and secondary root systems. Source: Based on Anderson & Garlinge (2000)

In waterlogged conditions, the nodal roots draw on oxygen in air spaces around the roots. If waterlogging is prolonged and the roots run out of oxygen they die.

### Root volume

The barley plant's fibrous root system develops horizontally and vertically, producing five to 10 times more surface area than plants with tap root systems (such as pulses). This is an advantage in less fertile soil or moisture-limited soil, as there is more chance of intercepting nutrients and moisture.

The roots are covered in microscopic hairs that greatly increase their surface area. When root hairs are factored in, the root system of one plant may have a total absorbing surface area of hundreds of square metres.

Early-sown crops are likely to have more extensive root systems than later sown crops, simply because of the extra time available for root growth.

### Vesicular-arbuscular mycorrhizae

Vesicular-arbuscular mycorrhizae (VAM) are fungi that occur naturally in soil and help make soil nutrients available to a plant by acting as an extension of the plant's root system. VAM increase the volume of soil so that the roots can explore and improve the uptake of nutrients, particularly phosphorus and zinc (see Table 2–1). VAM are particularly important in northern New South Wales. Barley has a very low VAM dependency and leaves very low VAM levels in the soil for the following crop.

### Rate and depth of rooting

In central NSW, the average rate of root growth (after crop establishment) has been measured at about 1.1 cm/day, resulting in a final depth of 1.4 m from a late-May sowing.

At the two-leaf stage the primary roots have a maximum depth of 25 cm, with abundant unbranched laterals 5 to 20 mm long (Figure 2–2).

Table 2–1. VAM dependency levels of common crops, and effects of VAM on production. Source: Thompson (1996)

CROP	MYCORRHIZAL DEPENDENCY	POTENTIAL YIELD LOSS %*	VAM LEVEL AFTER CROP
Linseed, Faba bean	Very high	>90	Low
Sunflower, Mungbean, Pigeon pea, Chickpea	High	60–80	High
Maize	High	60–80	Moderate
Sorghum, Cotton, Soybean, Sudan grass	Medium	40–60	Moderate
Field pea, Wheat, Triticale, Oats	Low	10–30	Low
Barley	Very low	10–30	Very low
Canola, Lupins	Nil	0	Very low

\* Without VAM in the soil. Source: Queensland Wheat Research Institute, Toowoomba (1996)

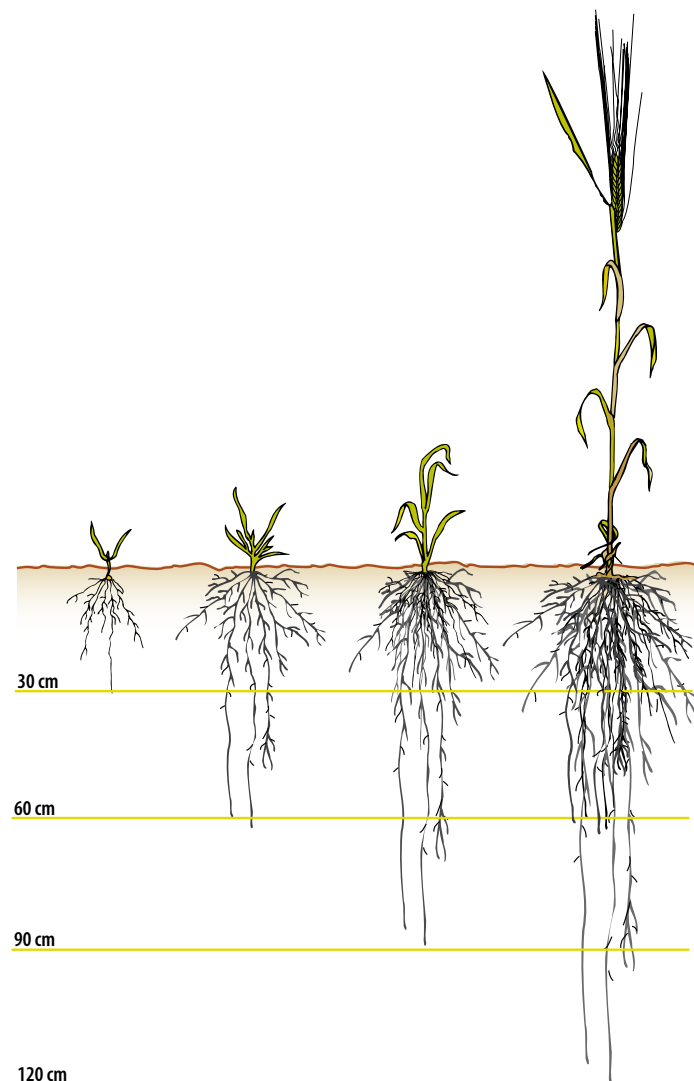


Figure 2–2. The increase in root volume as the barley plant develops. Source: Based on Weaver (1926)

By the time the plant is half grown (six-leaf stage) it has 10 to 17 primary and secondary roots reaching to 45 to 60 cm. A barley plant can have 15 lateral roots per 25 mm of primary roots. At this stage, the shallower roots have produced lateral roots 12 to 20 mm long.

At maturity, the primary roots are up to 1.4 m deep and finely branched, with a working depth and breadth of about 1 m.

There are a number of factors that can prevent roots from developing into the subsoil. They include lack of moisture, chemical constraints such as acidity or high aluminium levels, and physical constraints such as soil density or compaction.

In NSW, lack of moisture is a common cause of poor rooting depth, as roots cannot grow through dry soil, even if moisture exists in a band deeper down the profile. Where there is a chemical or physical constraint in the subsoil, moisture can be left at the end of the season. In dryland situations where the roots can't penetrate to the subsoil, barley plants can compensate to some extent by extending more roots into the surface soil.

Moist soil allows better penetration of the root system, so under irrigation roots are able to grow deeper, provided there are no subsoil constraints. Plants that develop fewer deep roots will have a greater dependence on in-crop rainfall after flowering, because moisture stored at depth cannot be extracted efficiently.

Roots branch profusely around moisture and sources of nutrients, especially phosphorus.

### Leaf growth

Following plant emergence, the shoot apex continues producing leaves until it undergoes a change to the reproductive phase, when the head is formed.

The main function of the leaves is to capture the energy of sunlight and, through photosynthesis, convert it to a form that can be used by the cells of the plant.

The total number of leaves produced on the main stem by the shoot apex varies from five to 15 or more. The final leaf number is determined by the variety's

response to day length and temperature, and by the basic vegetative period. Leaves continue to emerge even after the shoot apex has started to initiate the head.

The rate of leaf emergence is directly related to temperature. Leaf growth occurs between 0°C and 26°C, but it can vary with variety, light intensity and nutrition. In a barley cultivar such as Schooner, one leaf emerges on the main stem about every 90 degree days. (See *Thermal time* in this chapter.)

Leaves differ in size and have a limited lifespan. The seedling leaf is shorter and wider than later leaves, with a rounded end, smaller and blunter than the others. The flag leaf is often the smallest. Leaf size is greatly influenced by the environment, especially daylength. As leaves at the base of a stem die, new leaves form and unfold higher up the plant.

### Stem

The stem is cylindrical, consisting of hollow internodes separated by solid nodes. Typically there are five to seven internodes that elongate, of which the basal internode is the shortest and largest in diameter. The length of the internodes depends on genetic and environmental factors. These factors also influence the distance from the flag leaf to the base of the spike.

### Tiller growth (Z23–Z29)

The barley plant produces additional shoots called **tillers**, which develop from buds at the base of the stem. Some of these will produce a head (ear). There is a characteristic sequence of production and arrangement of tillers in barley. A bud develops in the axil of the coleoptile and each of the lower leaves of the main shoot. Usually only a proportion of these buds continue to grow and produce leafy tillers, the others remaining dormant. Tiller buds are not formed in the axils of those leaves on the elongated stem. 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 bases of main stems are the primary tillers, and these make the largest contribution to yield after the main stem itself.

Tiller numbers increase rapidly during the first few months after seedling emergence, peak shortly after floral initiation, diminish rapidly before head emergence, and finally stabilise until harvest.

When primary tillers reach three leaves they may also give rise to secondary tillers. Similarly, secondary tillers may go on to develop and give rise to tertiary tillers, although rarely does either contribute to grain yield. The number of tillers per plant depends on competition for resources such as water, nutrients and light. Tillers produce fewer leaves than the main shoot, and this tends to synchronise the development of the main shoot and tillers so that head emergence, grain set and ripening take place at approximately the same time in all tillers of the plant.

### *Importance of tillering*

Tillering is very significant in agronomic terms. Once the plant is established, it is a mechanism by which the barley plant can compensate for low plant numbers. The maximum number of tillers formed is genetically determined, but the actual number will be influenced by seasonal conditions, daylength, sowing date, plant population and nutrition.

Under conditions of moisture or nutrient deficiency the tiller buds remain dormant and plants produce few tillers. A good start followed by stress later in the growing season can mean that the number of tillers produced is excessive, resulting in small grain size.

### *End of tillering (Z29)*

Under optimum conditions, it is competition for light as the canopy closes that causes tillering to stop. This is generally at 50% to 60% light interception. The growth stage reached at the end of tillering depends on the variety. In late-maturing varieties (generally winter types such as Urambie), tillering ends when the plant is at the double-ridge stage (i.e. when cell division changes from producing leaf cells to producing reproductive cell structures. See *Apical development* in Chapter 3). Tillering stops in early-maturing varieties (spring

types) after the awn primordia stage (Z30). Tillering may also continue until the later growth stage in crops with very low plant densities, allowing for some compensation in tiller number and therefore yield.

### *Tiller mortality*

Not all tillers produce fertile heads. Tiller mortality often begins after floral initiation in the main shoot, as developing tillers compete for available assimilates against developing spikelets and florets on the main stem. The level of mortality depends on the resources available to the plant (nutrients, light and water). Later-formed tillers usually die first. Surviving non-productive tillers provide nutrient and carbohydrate reserves for grain-bearing tillers. Nutrients from dead tillers are recycled to support the fertile tillers.

The number of tillers that survive to form grain varies with variety, seasonal conditions and crop management. The response to seeding rate for a number of varieties at Gilgandra in 2006 is shown in Figures 2–3 and 2–4. The crop experienced considerable moisture stress and yields varied from 1.5 to 2.5 t/ha.

The decrease in number of heads per plant was not sufficient to offset the increased plant population, so that the number of heads per m<sup>2</sup> increased with higher seeding rates. Excessively high tiller numbers lead to small grain and high screenings in barley. In this experiment between 300 and 400 heads/m<sup>2</sup> was sufficient to maximise yield, depending on the variety.

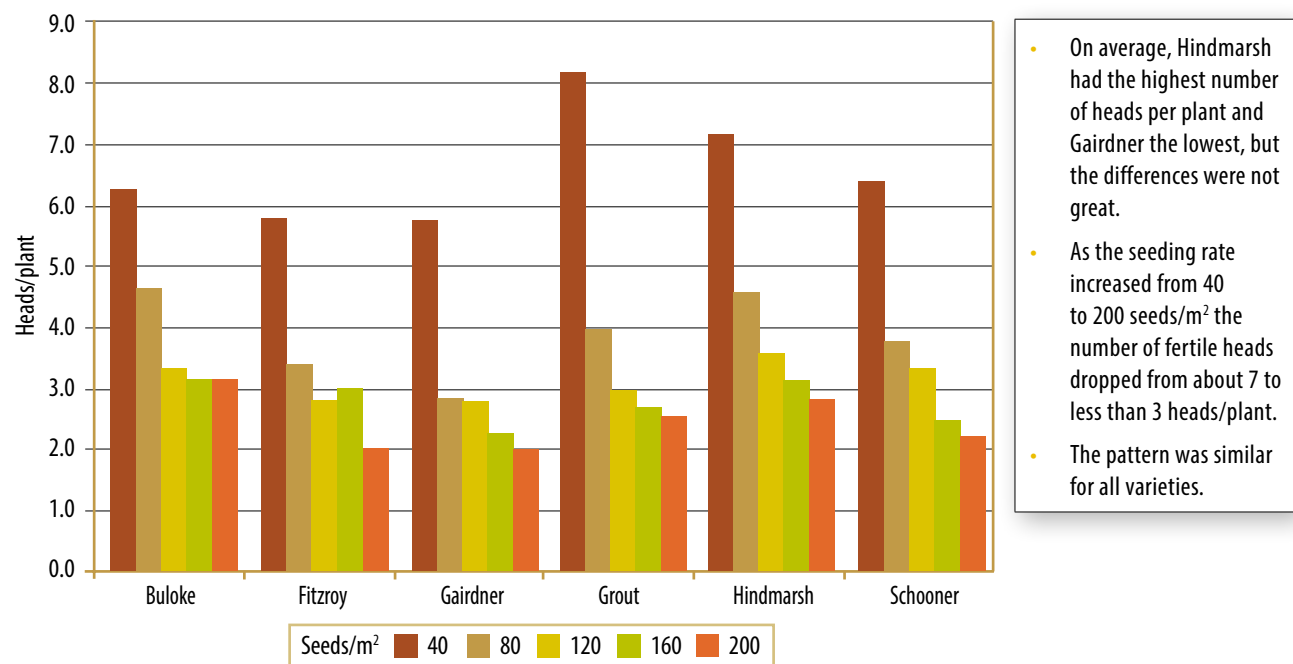


Figure 2–3. Heads per plant for several varieties of barley at different seeding rates/m<sup>2</sup> at Gilgandra in 2006. Source: Dr Neil Fettell (unpublished)

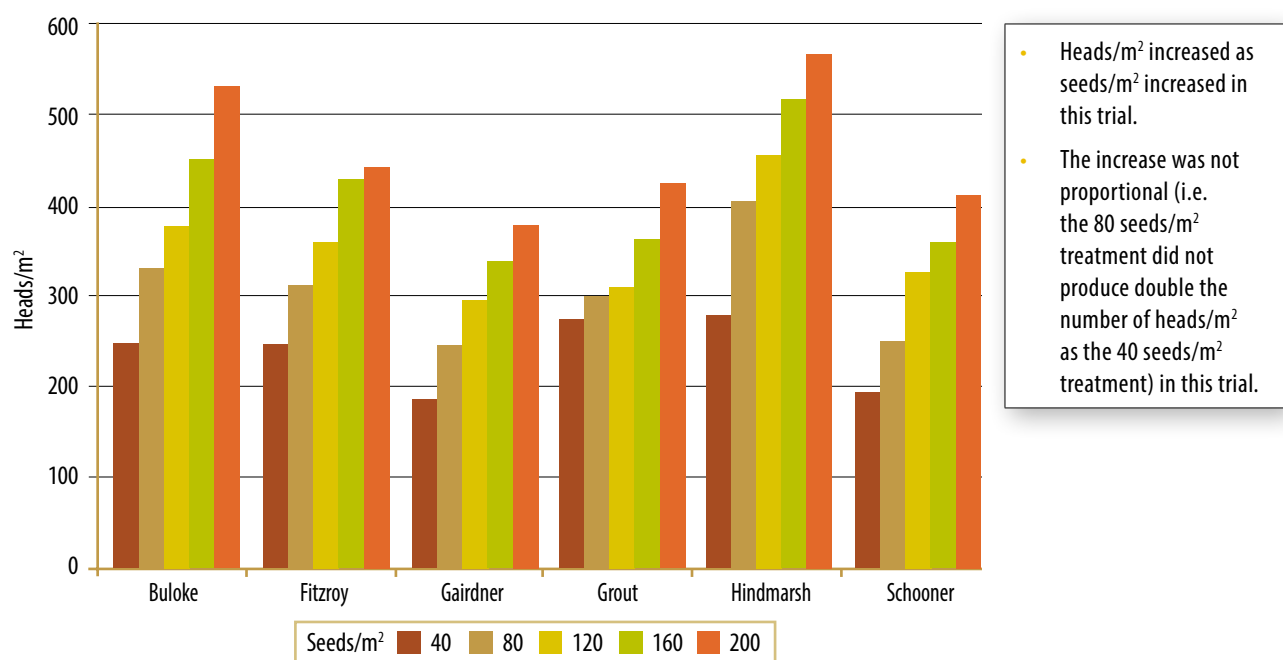


Figure 2–4. Numbers of heads/m<sup>2</sup> for several varieties of barley at different numbers of seeds/m<sup>2</sup>, Gilgandra 2006. Source: Dr Neil Fettell (unpublished).



## Factors affecting vegetative growth

Prior to establishment, plant growth is fuelled by reserves stored in the endosperm of the grain. Once the first two leaves have unfolded, growth relies on energy produced by the plant through photosynthesis.

### Photosynthesis and respiration

Plants get their energy to grow from sunlight captured by the leaves. Photosynthesis is the process whereby plants use this energy to convert carbon dioxide to sugars (Figure 2–5). These sugars are converted to cell-wall-forming substances that make up the leaves, stems, roots, and other plant parts. Excess sugars are stored as water-soluble carbohydrates.

When energy cannot be obtained from sunlight, such as at night, the plant draws on its reserves of starch and sucrose. This process is called respiration.

The rate at which the plant grows is closely linked to the amount of sunlight being captured by the leaves. Temperature influences the rate at which the chemical reactions of photosynthesis occur.

How well a leaf photosynthesises is influenced by factors such as variety and nutrition. For example, barley plants that are nitrogen deficient have yellow, stunted leaves. Yellow leaves have less chlorophyll (the pigment responsible for capturing sunlight energy), and small leaves simply catch less light.

### Transpiration

Transpiration is the plant water use or the evaporation of water from within a leaf. During transpiration, water evaporated from the cell walls within the leaf moves onto the leaf airspaces and out through the leaf **stomata**.

Transpiration and photosynthesis are related. Leaf stomata need to be open to allow water vapour to move out and to allow carbon dioxide for photosynthesis to move in. When plants are transpiring,

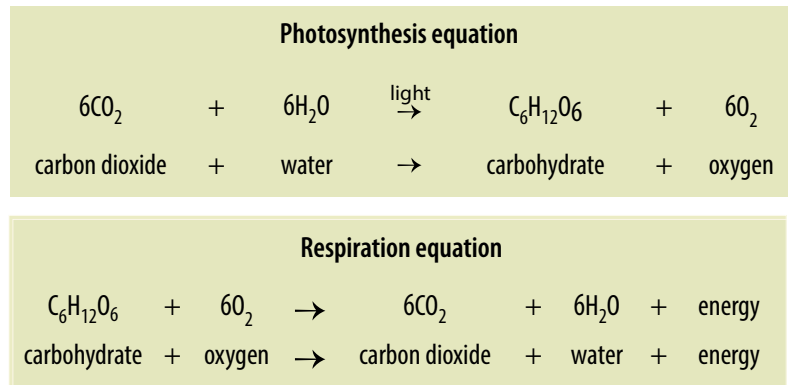


Figure 2–5. Equations for photosynthesis and respiration.

water is drawn up from the soil all the way to the leaves to replace the water lost to the atmosphere.

Transpiration is slower in cool conditions with high humidity, and faster in windy, hot conditions with low humidity. These hot conditions are unfavourable when combined with low soil moisture, because as the soil moisture drops the stomata close to preserve moisture, and photosynthetic productivity is lost.

### Leaf area

The photosynthetic capacity of the crop is related to the size of the leaf area and the length of time this area is maintained. Maintenance of the green leaf area is essential for production of the sugars used during grain-filling.

Leaf area is influenced by the rates of leaf appearance, tiller production and leaf expansion. Generally, barley has a higher leaf area than wheat up to flag leaf emergence, giving it a greater competitive advantage against weeds.

Leaf area is measured by the leaf area index (LAI), which is the amount of leaf area in a crop canopy compared to the area of ground. If a square metre of crop was cut at ground level and the leaves were laid out flat touching each other, with no gaps, then the area covered is the leaf area index. If the leaves cover 3 m<sup>2</sup>, the crop has a leaf area index of 3.

#### Stomata

Tiny pores on the leaves that allow gas exchange.

The leaf area index of a crop determines its water use. The larger the leaf area index, the more water that is used during the vegetative growth stage. In dryland crops, a large area of leaf in early vegetative development can use up water that may otherwise be available for flowering and grain-filling. So a balance needs to be reached between a large leaf area to maximise photosynthesis and the production of sugars, and maintaining sufficient soil moisture for grain fill.

### Moisture

Availability of soil moisture has major interactions with the rate of transpiration and therefore photosynthetic production.

#### *Moisture stress*

Moisture stress slows photosynthesis and leaf area expansion, reducing dry matter production. It also limits root growth, which reduces nutrient uptake. This is important in areas with low rainfall. The period of crop growth is restricted at the start of the season by lack of rainfall and at the end of the season by water deficits and high temperatures. There is therefore little scope in these areas to lengthen the period of crop growth to increase dry matter production and yields.

#### *Waterlogging*

Barley is very susceptible to waterlogging. It is less tolerant than wheat or oats. Barley should not be grown on soils where waterlogging is likely to occur for periods of more than 2 weeks, or on irrigation layouts with poor drainage.

Waterlogging occurs when rainfall exceeds the infiltration rate, waterholding capacity, and internal drainage rate of the soil profile. Waterlogging fills the air spaces of the soil with water, reducing the oxygen concentration. This limits root function and survival, resulting in decreased crop growth or plant death. Availability of

nitrogen and other nutrients may also be reduced. The lack of nutrients slows the rate of leaf growth and accelerates leaf death. Tiller initiation is also slowed, reducing the growth and survival of tillers. These conditions contribute to yield reductions. The amount of reduction depends on the stage of plant development when the waterlogging occurs, the duration of the waterlogging, and the soil quality.

### Nutrition

Nutrition affects the rate of plant development and total dry matter accumulation. Nutrients need to be supplied within an optimal range from germination onwards to maximise plant growth. Nutrients are divided into two main groups: macronutrients (required in large amounts by plants) and micronutrients (required in small amounts).

Most nutrient uptake is through the root system. Uptake of nutrients through the leaves is usually insignificant, apart from a few minor nutrients such as copper, zinc, manganese and molybdenum.

The mobility of nutrients in the soil determines the way in which plants take them up. This has implications for fertiliser use and placement in the soil. For plants to take up nutrients such as phosphorus, copper and zinc, which have low mobility in the soil solution, the roots need to grow through the soil in contact with nutrients.

It is important to balance crop nutrition with nutrient removal from the previous crop. Table 2–2 shows the amount of nutrients removed in each tonne of barley.

#### *Nitrogen*

Nitrogen supply influences nearly all components of the growing barley plant. Nitrogen is required for the production of chlorophyll and for carbohydrate synthesis in the plant, and during the vegetative

Table 2–2. Nutrient removal (kg) for each tonne of barley.

	N	P	K	S	Mg	Ca
Barley grain	19.2	2.88	4.39	1.1	1.08	0.35
Cereal hay	20	2.0	12.0	1.5	3.0	12.0

Source: Price (2006).

stage it is required for root growth, leaf growth and tillering.

Nitrogen nutrition is slightly more complex than with other nutrients (such as phosphorus), especially in dryland situations, because there is a strong connection between plant growth, nitrogen supply and available soil moisture. However, the supply of nitrogen can be managed to manipulate growth and development to optimise yield. For example, for malting barley, nitrogen needs to be supplied early in the growth of the plant so that yield increases, without increasing the protein content of the grain.

Nitrogen readily moves within the plant to areas of active growth. This is why nitrogen deficiency symptoms first appear as yellowing of the older leaves as nitrogen is moved to younger, actively growing tissues.

Barley plants take up most of their nitrogen requirements during the vegetative growth stage, with nitrogen demand being particularly high from early tillering until head emergence. Nitrogen uptake after head emergence is generally small under Australian conditions, unless there are very high levels of soil mineral nitrogen and soil moisture.

Nitrogen supply and light intensity control the rate and pattern of development of an individual tiller. Where there is adequate nitrogen and light, a tiller's development is continuous. Where light or nitrogen are limiting, growth is not continuous and instead occurs in intervals.

Barley plants that receive nitrogen at excessive levels early in the season (Z20–30) often respond by producing large numbers of tillers and less root growth. This has implications for dryland crops: a larger area of leaf uses a larger quantity of water, so water availability may be restricted at the flowering stage.

Adequate nitrogen in the later stages of growth increases the length of time for which the crop has green leaves and maximises photosynthesis, provided that moisture is not limiting. Split nitrogen applications can be useful in reducing excessive early growth but maintaining green leaf area into grain-filling. Care

needs to be taken with applying late nitrogen to malting crops, as there is a risk of exceeding grain protein delivery specifications.

### *Phosphorus*

Phosphorus is essential for almost every plant function. During vegetative growth it is essential for the energy storage and transfer system of plant cells, and it is needed for the rapid cell division and expansion taking place.

The amount of phosphorus available depends on the soil type (as phosphorus reacts with the soil in a complex way). As phosphorus comes into contact with the soil it can become chemically bound into the soil, with as much as 50% converting to forms unavailable to the plant. This needs to be taken into account in determining the rate of application.

Phosphorus does not move through the soil solution and therefore needs to be supplied into the root zone for it to be taken up by the plant. In no-till situations, without tillage to spread fertiliser evenly in the soil, fertiliser placement and depth below the seed band are important.

Research has consistently shown that an economic grain yield response to applications of phosphate fertilisers is unlikely if fertiliser application is delayed for more than 10 days after sowing a cereal crop into moist soil.

Symptoms of phosphorus deficiency in barley are usually non-specific and difficult to diagnose. As phosphorus is needed for early plant growth, deficient plants consequently are slower to reach specific growth stages and have fewer tillers; they are shorter and have lower head and grain numbers. These plants tend to put more resources into root growth than shoot growth in the search for more phosphorus. Leaves also become dark green.

Phosphorus deficiency also leads to poor uptake of other nutrients and reduces water-use efficiency and drought tolerance. Acute phosphorus deficiency can cause leaf death and delay flowering.

**Turgor pressure (turgidity)**

The pressure of the cell contents against the plant cell wall. It is determined by the water content of the plant vacuole.

**Vacuole**

A membrane-bound sac that plays a role in turgor pressure in the plant cell. When a plant is well watered, water collects in the vacuoles, making the plant rigid. Without enough water, pressure in the vacuole is reduced and the plant wilts.

**Lignification**

A hardening of the plant cell wall through the accumulation of lignin, a plant polymer.

**Potassium**

Potassium is a major plant nutrient that is required in similar levels to nitrogen. It is used in many plant processes, including photosynthesis, transport of sugars, maintenance of plant **turgor** and enzyme activation. Potassium is particularly important in the regulation of stomata in the leaves. Plants that are deficient in potassium cannot use other nutrients or water efficiently. They are less tolerant of stresses such as drought, waterlogging, pests and diseases.

Potassium, unlike nitrogen and phosphorus, is found in adequate levels in most Australian soils, so deficiency is rarely seen. Potassium is very mobile in plant tissues. In deficient plants it is moved to new growth, so deficiency symptoms appear first in older leaves. The symptoms are yellowing and death (necrosis) of the tips of oldest leaves. In barley, necrotic areas can have a red appearance. Stems may be weakened, resulting in lodging. Restricted potassium supply during early growth stages may be more harmful than later deficiency. Potassium deficiency can affect leaf area, the amount of dry matter produced in the upper internodes and heads, the number of grains per head, or the seed weight. The root systems of potassium-deficient plants may also be poorly developed.

Potassium requirements are greatest during the late vegetative and flowering stages.

**Sulfur**

Sulfur is part of every living cell and is a component of three of the 21 amino acids that form proteins. Sulfur deficiency in barley is rarely seen, but if high-analysis fertilisers are continually used then sulfur levels can become low enough to restrict growth. Sulfur is not mobile in the plant tissues, so deficiency symptoms appear first as pale young leaves; growth and maturity are also slowed. With severe deficiency the whole plant becomes yellow and the stems appear reddish.

**Micronutrients**

There are a number of micronutrients essential to plant growth. They include molybdenum, zinc, copper, manganese and boron. With any of these nutrients

there is a fine line between adequate nutrition and toxicity. Deficiencies are not common, but where they occur, yield loss can be substantial. Symptoms are often hard to diagnose and sometimes require a tissue test to confirm.

**Molybdenum** is essential for plants to use nitrate nitrogen and is required in cereals for grain formulation. The heads of molybdenum-deficient plants are often empty or have shrivelled grain. As molybdenum is important in nitrogen metabolism of plants, deficiency can initially look to have the same symptoms as nitrogen deficiency. Molybdenum is less soluble in acidic soils, so deficiency is more likely to be seen in these soils. Molybdenum is used early by the plant, so seed coatings can be sufficient to address deficiencies.

**Manganese** is used in many metabolic processes in the plant, including in chlorophyll production. It is relatively immobile in the plant. Manganese toxicity is more common than deficiency, particularly in waterlogged soils. It appears as yellowing of the leaf margins but is more common in other crops, such as canola. Use of a planned foliar spray rather than seed treatment is the preferred strategy for combating an expected deficiency.

**Zinc** is involved in the enzyme systems of plants. Zinc deficiency usually shows as a pale area in the middle of the leaf, extending towards the new growth. It looks like a long, pale green strip on each side of the mid-vein of the leaf and is more common in alkaline soils with a pH greater than 8.5. Zinc can be applied as a seed dressing, blended with compound fertilisers, or applied as a foliar spray.

**Copper** is also essential in many plant enzymes and for **lignification**, which gives a plant its structural strength. Copper-deficient plants can have weak stems and limp leaves. Copper deficiency also affects pollen development. Grain-filling is restricted, as pollen sterility causes uneven grain set or failure of grain set. Copper deficiency can be confused with moisture stress, frosting or molybdenum deficiency symptoms.

## Leaf and root disease

Paddock selection and crop rotation, combined with the use of disease-resistant varieties, are the best strategies to minimise disease. A table of disease ratings for current varieties can be found in Industry & Investment NSW's *Winter crop variety sowing guide*. Seed treatments can be used to prevent some diseases, and foliar fungicides can be used to treat most foliar diseases.

Disease can affect the growth and development of barley by disrupting one or more of the plant systems. If the roots are affected the barley plant has less ability to absorb nutrients and water, so growth is restricted. If the leaves are affected then the ability to photosynthesise is also compromised.

A number of diseases can affect barley in the early growth stages. They include root diseases such as rhizoctonia, crown rot and take-all. Viruses such as barley yellow dwarf virus are more prevalent in early-sown crops, as these diseases tend to occur when the weather is warmer and the carriers of such viruses are more prevalent. Foliar diseases such as rusts, scald, mildews, net blotch and the spot form of net blotch can affect the plant at any growth stage. Nutrient-deficient plants are less resistant to pests and diseases.

## Grazing

Barley can be grazed to fill the winter feed gap in a mixed farming system. Long-season varieties with a winter habit (e.g. Urambie) can be grazed without a major grain penalty, provided that nutrients and water are not limiting and the crops is not grazed after stem elongation has commenced. Barley crops can be grazed from 6 to 8 weeks after sowing, depending on the amount of root anchorage.

Barley can be grazed without reducing yield. Grazing crops more intensely for a shorter period of time (4 weeks) is more profitable than grazing for 6 weeks. Longer grazing periods tend to result in a greater yield penalty. Lengthy and intensive grazing can also delay the flowering date. This can be a problem if

grain fill runs into hot weather or there is a short spring period.

Grazing may reduce the water use of a crop. When the vegetation is removed, water is preserved in the profile for use during grain fill, mainly because there is less dry matter to transpire.

## Factors affecting plant development

The main stem of the barley plant is used to determine the growth stage of the plant and the timing of development. The rate at which a barley plant develops or moves from one growth stage to the next sets the limit for canopy growth and ultimately yield. The major factors affecting the length of each growth stage are vernalisation, photoperiod, thermal time and variety characteristics. The significance of these factors depends on whether the barley is a spring or winter type.

Leaf and tiller appearance, senescence (the aging and drying of leaves and non-productive tillers) and plant height are components of the canopy structure that are determined by variety and sowing date.

## Vernalisation

In varieties that are vernalisation 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 (prostrate) growth habit. In Northern Hemisphere winters this ensures that the plant remains protected beneath the snow.

When the cold requirement is met, the plant moves into its reproductive stage and begins to initiate the floral parts. The number of cold hours, or 'vernalisation response', required to reach floral initiation varies greatly among winter varieties, probably depending on the region where the variety originated.



Sowing date has less effect on flowering date in varieties that require vernalisation. These varieties are safer to sow earlier than vernalisation-insensitive spring types, as they do not go into head until their cold requirement has been met. This reduces the risk of frost damage at flowering and grain fill.

The growing point of winter barleys remains in the crown or below the soil level until the vernalisation requirement has been reached, which is why they are used for grazing. Tiller death is minimal provided grazing is stopped once the growing point begins to elongate.

## Photoperiod

The timing of head emergence in barley is also controlled by the plant's response to day length. Photoperiod is the number of hours of daylight. Barley is a 'long day' species. Its development rate is fastest under long days because fewer leaves are formed on the main shoot, initiating the reproductive stage earlier. Under short days more leaves are formed, the period of leaf initiation is extended, and floral initiation takes place later.

Photoperiod can affect the growth and development of barley in three distinct ways, by:

- causing changes in the rate of leaf area expansion and dry matter production
- providing a cue for the start of the reproductive phase
- changing the rate of reproductive development

Photoperiod is the major environmental influence on flowering time in spring barleys. In Australia, these barleys are grown in short days (winter) but development is hastened as the photoperiod increases in late spring. Some winter barleys are photoperiod sensitive once their cold requirements have been met.

Varieties respond differently to photoperiod. An understanding of the photoperiod sensitivity and basic vegetative period of a variety helps to explain the recommended sowing windows. Varieties that have high

photoperiod sensitivity tend to have a wider sowing window, as they can 'speed up' their development if sown later.

## Basic vegetative period

A third factor that controls development in barley is the basic vegetative period. The basic vegetative period reflects the inherent time to flowering of a variety when it has had its vernalisation requirement satisfied and is grown under long days. It is reflected in the minimum number of leaves formed when a variety is grown under these conditions.

As well as forming more leaves before flowering, varieties with a long basic vegetative period tend to produce leaves at a lower rate, further delaying flowering. This response can be accentuated by adding genes for daylength insensitivity and vernalisation.

Varieties such as Franklin, and to a lesser extent Gairdner, have long basic vegetative periods and relatively low sensitivity to day length. They therefore need to be sown early. Urambie can also be sown early, as it has a vernalisation requirement, but it becomes quicker to flower with later sowings.

By contrast, varieties with a shorter basic vegetative period (e.g. Schooner) are better suited to later sowing, particularly when they also have high day-length sensitivity.

## Thermal time

Thermal time is a calculation of accumulated temperature. It helps explain the relationship between plant development and temperature. Temperature affects all developmental phases. As temperature increases between a range of 0°C and 30°C, the growth rate increases. Below 0°C there is little growth, and above 30°C the growth rate levels off. This linear response means that the development of the crop can be predicted by adding up the number of thermal units that the crop has experienced since it was planted.

Thermal time is calculated as the average daily temperature minus the base temperature and is recorded as degree-days (°Cd). The base temperature

is the minimum temperature at which the plant grows. For barley it is 0°C during vegetative growth and 3°C in the reproductive phase. See *In the paddock – Thermal time* at the end of this Chapter for more information.

The flowering time responses of four varieties to sowing time (at Condobolin) are shown in Figure 2–6. Schooner, which has a short-medium basic vegetative period, was the quickest to head emergence at all sowing dates. Gairdner, which has a medium-long basic vegetative period, was the slowest. Tantangara was also slow to flowering from early sowings, but its higher photoperiod sensitivity allowed it to flower earlier than Gairdner when sown late.

At Condobolin, approximately the third week of September is a preferred time for head emergence. This is the range between the two horizontal lines in Figure 2–7. To achieve this, Gairdner and Tantangara would need to be sown in early May, Baudin in mid May, and Schooner in mid-late May.

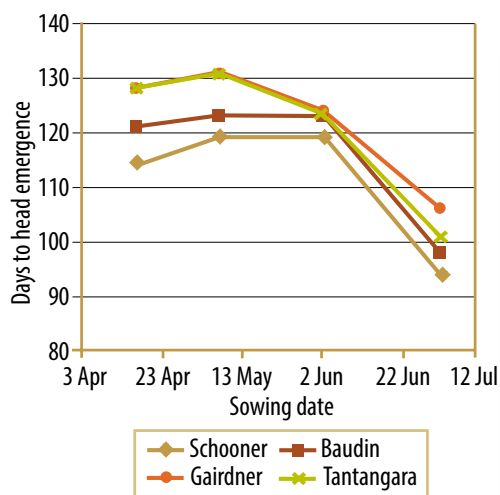
Where sowing was delayed until late June, Schooner responded to lengthening days and higher temperatures by shortening its vegetative period, flowering only 10 days later than the preferred time. Gairdner was much less responsive and did not flower until mid October.

## Sowing time

The interaction of variety characteristics and environmental conditions determines the phasic development of a crop and, in particular, its flowering time. Recommended sowing times are determined by assessing the flowering times of varieties in different environments at a range of sowing times. The maturity times of varieties available in NSW vary greatly. Consequently there is a wide range of optimum sowing times. Table 2–3 is an example of the sowing windows for a number of varieties in central NSW. Up-to-date tables are published each year in Industry & Investment NSW's *Winter crop variety sowing guide*.

Sowing a variety at a time outside the sowing window can result in flowering at a less than ideal time of the year. Flowering too early increases the risk of damage by frost, and flowering too late increases the risk of high temperatures and water stress during flowering and grain-filling.

Yield reductions of up to 5% a week can be expected when sowing is delayed beyond the end of the recommended period for each variety.



- The number of days from sowing to head emergence decreased the later the varieties were sown.
- When sown in April, varieties took between 115 and 130 days to head emergence.
- With sowing in late June, the number of days to head emergence fell to between 90 and 100 days.

Figure 2–6. Effect of sowing time on days to head emergence in various varieties of barley at Condobolin. Source: Dr Neil Fettell (unpublished).

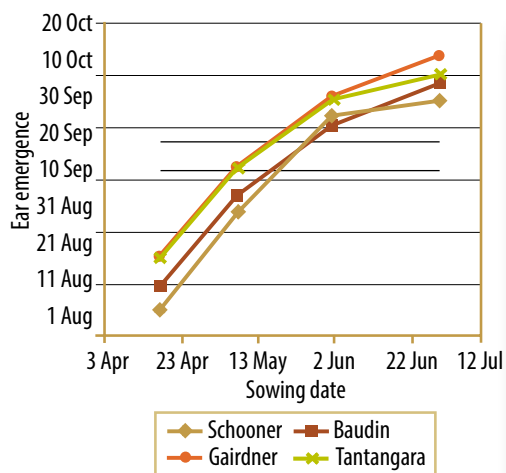


Figure 2–7. Effects of sowing date on time of ear emergence in various varieties of barley at Condobolin. The two horizontal lines delineate the preferred time for head emergence. Source: Dr Neil Fettell (unpublished).

- The two horizontal lines border the preferred time for head emergence at Condobolin.
- When sown before the middle of May, varieties reach ear emergence before the optimum time at Condobolin and are at risk of frost.
- Varieties sown after the start of June reach ear emergence after the ideal time and will fill grain at a hotter time of the year.

Table 2–3. Recommended sowing times for varieties in southern New South Wales

VARIETY WEEK	MARCH				APRIL				MAY				JUNE				JULY		
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
Yambla, Urambie		>	★	★	★	★	★	★	★	★	★	<							
Gairdner, Binalong, Capstan							>	★	★	★	★	<							
Tantangara, Cowabbie, Baudin								>	★	★	★	★	<	<					
Mackay, Fitzroy, Tulla, Tilga, Flagship, Fleet, Buloke, Schooner, Hindmarsh									>	★	★	★	★	★	★	★	<	<	<
Grout										>	★	★	★	★	★	★	★	<	<

> Earlier than ideal, but acceptable. ★ Optimum sowing time. < Later than ideal, but acceptable. Yambla and Urambla can be sown from early/mid March is grazed.

Source: Industry & Investment NSW (2009).

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## IN THE Paddock

The following are some examples of what can be done in the paddock to demonstrate the stages of growth and development that have just been discussed. These are practical exercises to help farmers assess the progress of their crops at the vegetative stage.

### Examining the root system

*Aim: to check the root system of the crop for the presence of secondary roots and for signs of disease.*

1. Carefully dig up 10 plants.
2. Wash soil away from the roots.
3. Find the primary root and determine whether there are secondary roots.
4. Look for the sub-crown internode.
5. Do the roots look healthy? Is there any sign of disease?
6. At flowering, excavate a hole around a plant and trace the root depth. How deep are the roots? Are there soil limitations to root growth?

### Assessing plant growth stage

*Aim: to accurately assess the current crop growth stage. Always assess the main stem.*

1. Carefully dig up a plant.
2. Identify the main stem and the tillers. Turn the plant upside down and grab the longest leaf. This leaf is attached to the main stem. The main stem should also be the thickest. The other stems are the tillers.
3. Count the number of fully unfolded leaves on the main stem.
4. Count the number of tillers (if any).
5. Look closely at the oldest leaf and find the auricle and ligule.
6. Compare with Zadoks decimal code and record the growth stage in the table below.
7. Repeat this procedure with five plants and record the results.
8. Repeat this exercise with different varieties and different sowing dates.

GROWTH STAGE		
PLANT	Paddock 1	Paddock 2
1		
2		
3		
4		
5		

## IN THE Paddock

### Tiller counts

*Aim: to assess the number of tillers/m<sup>2</sup> to compare different nitrogen rates, varieties or sowing rates.*

1. Assess the crop when it is at Z30.
2. Count the number of tillers per plant along 0.5 m of row.
3. Do this at 10 locations within a paddock.
4. Add the 10 counts together and divide by 5 to give the average number of tillers/m of row.
5. Multiply the tiller counts by the row spacing factor to convert tillers/m of row to tillers/m<sup>2</sup>:
 

17.5 cm = 5.71	20 cm = 5.00	33 cm = 3.03
22.5 cm = 4.44	25 cm = 4.00	36 cm = 2.77
27.5 cm = 3.36	30 cm = 3.33	40 cm = 2.50
6. Repeat in a second paddock and record the results.

TILLERS		
COUNT	Paddock 1	Paddock 2
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Total		
Average per m row		
Tillers/m <sup>2</sup>		



## IN THE Paddock

### Dry matter assessment

*Aim: to determine what quantity of dry matter is available to graze. Assess the crop when its root system is firmly anchored.*

1. Using a quadrat, cut a known area to ground level.
2. Repeat this process at five locations.
3. Mix all the samples together and weigh out a 150 g subsample. This is the wet weight.
4. Very carefully dry the subsample in a microwave. Place a cup of cold water in the microwave with the sample. Replace the water when it begins to boil.
5. Calculate the dry matter percentage by using the following formula:

$$\text{Dry matter \%} = \frac{\text{weight of dry sample (g)} \times 100}{\text{weight of wet sample (g)}}$$

6. The quadrat conversion factor is:
  - a 30 cm × 50 cm quadrat = 0.15 m<sup>2</sup> or 1/66,666th ha, so × 67 to get kg DM/ha
  - a 50 cm × 50 cm quadrat = 0.25 m<sup>2</sup> or 1/40,000th ha, so × 40 to get kg DM/ha.

HERBAGE MASS (kg DM/ha)			
CUT	WET WEIGHT	DRY MATTER %	HERBAGE MASS
1			
2			
3			
4			
5			
Average			

### Monitoring for pests, diseases and injury

1. At regular intervals, walk a transect across the paddock.
2. Stop at five locations and check the plants for signs of insect damage or disease.
3. Look for nutrient deficiency symptoms and herbicide effects.

## IN THE Paddock

### Thermal time

*Aim: to calculate the accumulated thermal time for a location.*

- Using the records from the nearest meteorological station, record the daily maximum and minimum temperatures for each day.
  - If the minimum temperature is less than 0°C, then use 0°C as the minimum temperature in the equation
  - If the maximum temperature is above 30°C, then use 30°C as the maximum temperature in the equation

- Calculate the average temperature for each day:

$$\frac{\text{Daily maximum temperature} + \text{daily minimum temperature}}{2}$$

- From the daily temperature, subtract the base temperature, which for barley is 0°C.

- Add the resulting growing degree-days together to give the accumulated degree-days.

DAY	MAXIMUM	MINIMUM	MEAN	ACCUMULATED DEGREE-DAYS
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
TOTAL				

# 3. Reproductive development

by Phil Bowden and Neil Fettell

## Chapter Snapshot

### Reproductive development (Z13–Z69) – 44

*Floral initiation (Z13–Z16), Spikelet initiation, Awn primordium stage, Head at 1 cm (Z30), Stem elongation (Z31–Z36), Floret development, Booting and head emergence (Z41–Z60), Anthesis*

### Factors affecting reproductive development – 48

*Moisture stress, Temperature, Flowering time, Nutrition, Herbicides*

### References and further reading – 53

#### In the paddock – 55

*Identifying Z30 (the awn primordia stage), Nitrogen topdressing, Flowering, Modelling flowering time*

## Introduction

*The reproductive phase of the barley plant continues the process of determining final yield. Vegetative growth prepares the plant to form the developing head and yield components. Management and environmental conditions during vegetative growth, and environmental stresses during the reproductive phase, determine the maximum yield that can be set by the plant within its genetic potential.*

*Knowledge of the stages of reproductive development helps farmers manage the plant during this phase to minimise the effects of various stresses and maximise yield.*

## Learning Outcomes

At the end of this chapter, you will be able to:

- recognise the change from vegetative growth to reproductive development
- identify stem elongation, floret formation and anthesis
- describe the effects of frost, heat and moisture on reproductive development
- determine the flowering window for a variety, taking into account location
- assess the growth stage of a crop, particularly for the purposes of nitrogen topdressing, herbicide application and removal of grazing stock.

## Reproductive development (Z13–69)

The reproductive phase begins when the shoot stops forming leaves and begins forming a head; this process is known as floral initiation. Within the head are the developing floral structures. This is a complex phase with a number of developments happening at the same time. (See *Introduction*, Figure iv, which shows the development stages of the barley plant, including the overlap in reproductive development).

### Floral initiation (Z13–Z16)

The first sign of floral initiation is the formation of double ridges on the mounds on either side of the apical dome.

### Double-ridge stage (Z13–16)

In the vegetative stage, the shoot apex consists of a series of single ridges that produce leaves. When the apex begins to elongate or extend, the ridges form too quickly to grow into leaves, so the cells reorganise to produce the head instead. The plant now begins its reproductive phase.

The shoot apex is not visible to the naked eye. It is only about 0.5 mm long and can be seen only under a microscope.

During the double-ridge stage (Figure 3–1) a series of paired ridges or swellings develop on the elongating apex. The upper ridge swells and becomes the spikelet, whereas the lower leaf ridge stops developing and disappears. At this stage the apex is 1 mm long.

The double-ridge stage may last for several weeks. The stage occurs when the plant has three to six fully expanded leaves.

### Spikelet initiation

The first spikelet ridges, which develop into the first spikelets, initiate in the centre of the apex and then form progressively towards either end of the head. This pattern of development continues into flowering and grain filling, so that the most advanced and mature components are in the centre of the head.

### Triple-mound stage

At the triple-mound stage each double ridge differentiates further into three distinct bumps or mounds. The central mound will form the median spikelet and the other two mounds will become the lateral spikelets (Figure 3–2). In two-row barley varieties these lateral spikelets are sterile, but in six-row varieties they develop and are fertile. At this stage the developing head is 1.5 mm long.

### Glume, lemma and stamen primordium stages

During these three stages the developing head continues to grow, to about 3 mm long. The structures that form the glumes and lemma (which enclose the floral parts) and stamens appear. In barley, unlike in wheat, the glumes are small, reflecting their small size at maturity.

### Awn primordium stage

At this stage the head is 4 mm long and the plant has between 7 and 12 leaves.

The meristematic dome (at the tip of the head) has ceased dividing. The head has its full complement of spikelets, and the initiation of all the structures within the median spikelet is complete (Figure 3–3).

**Primordium/Primordia**  
Organ/organs in their earliest stage of development.

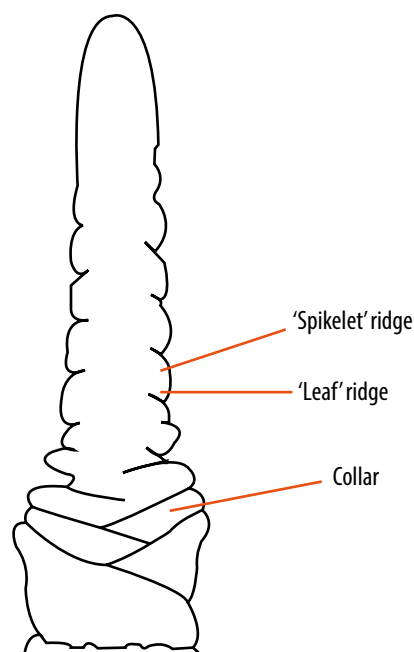


Figure 3–1. Profile view of an apex at the double-ridge stage.  
Source: Kirby and Appleyard (1984)

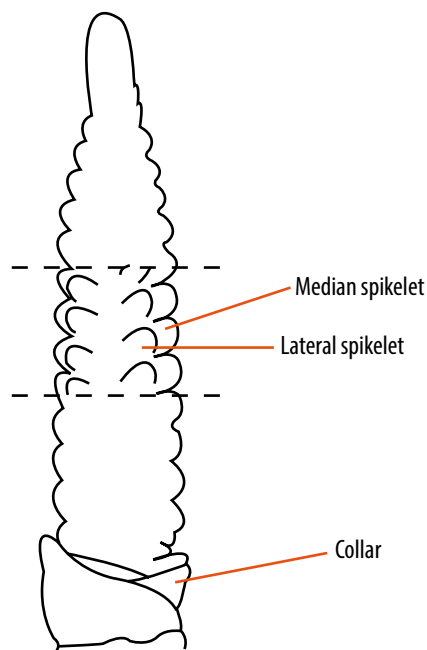


Figure 3-2. Mid-part of the apex in the triple-mound stage.  
Source: Kirby and Appleyard (1984)

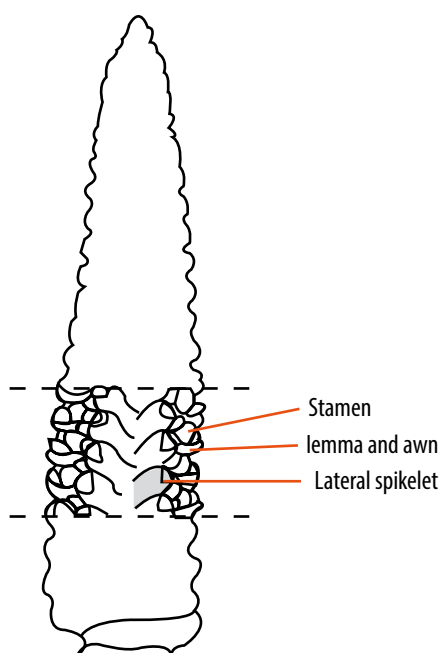


Figure 3-3. Awn primordium stage.  
Source: Kirby and Appleyard (1984)

The head has about 45 spikelets, which, although they have been formed over a long period, are at about the same stage of differentiation. Each spikelet contains a single floret. In two-row barley, only the central spikelets are fertile. Some of the developing spikelets will die before anthesis.

Awn development has begun. The awns develop from the tip of the lemma. The awns grow rapidly, soon becoming as long as the head.

This stage is similar to the terminal spikelet stage in wheat. However, barley does not form a terminal spikelet.

### Head at 1 cm (Z30)

As the plant reaches the awn primordial stage, stem elongation starts. Rapid stem growth brings the head from belowground to aboveground. When the head is 1 cm above the ground it is large enough to be seen in the field.

Because the awn primordium stage cannot be detected in the field or related to a specific Zadoks code, the head at 1 cm is a commonly accepted indicator. The head can be seen by slicing the main tiller with a sharp blade and peeling back the unemerged leaves (Figure 3-4).

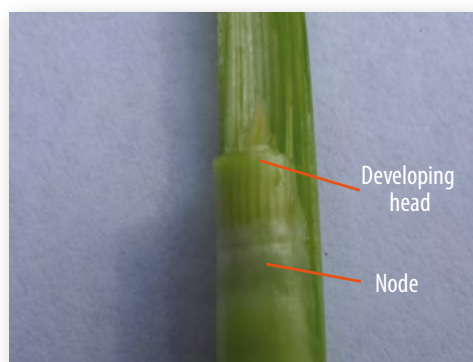


Figure 3-4. Developing head at 1 cm above the ground (Z30).  
Photo: Tim McNee



The presence of a head of this size is a useful indicator for removal of grazing animals, application of nitrogen, application of growth regulators, and timing of application of many herbicides (see *Herbicides* later in this chapter).

### Stem elongation (Z31–Z36)

Stem elongation begins at the end of the awn primordium stage. It is the result of elongation of the internodes. The crown consists of eight to 14 nodes stacked closely above one another, separated by internodes less than 1 mm long. When the internodes elongate the individual nodes become detectable.

The node (Figure 3–5) is the part of the stem where the leaf is attached. Above the node is the leaf base. When you run your fingers up the stem it can be felt as a hard lump. The developing head is found in the stem above the highest node.

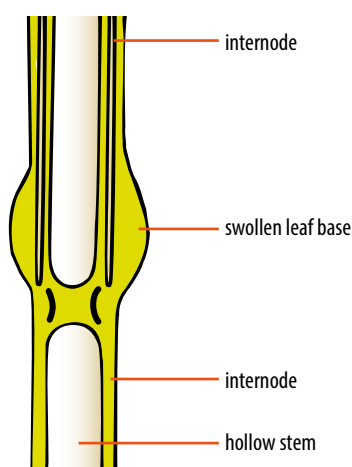


Figure 3–5. Cross-section of the stem, showing the node and the swollen leaf base that can be felt as a hard lump.  
Source: Kirby and Appleyard (1984)

The growth of the first five or six internodes elongates the stem and pushes the head up. The lower internodes remain compressed at the base of the stem. The number that elongate depends on sowing date and variety.

Stem elongation occurs in an ordered sequence. An internode begins to elongate when the leaf associated with it reaches full size. When this internode is half its final length the one above it begins to grow, and this continues until the last internode (the peduncle) is fully elongated and the stem is at its final length. Each internode is longer than the last, so that the peduncle is the longest of all.

Stem elongation is a time of intense competition for nutrients and moisture. The head is growing in size (Figure 3–6). Growth is slow in the early stages and increases greatly as head emergence approaches.

The head is sensitive to environmental stress – in particular, deficiencies in moisture and nitrogen. If stress occurs, the secondary and weaker tillers of the plant abort, whereas the main stem and the stronger primary tillers continue to grow. This is an example of the barley plant's ability to adjust to environmental conditions. The death of weaker tillers diverts resources to the larger tillers. The result is fewer heads per square metre but a greater chance of the remaining grain filling properly.



Figure 3–6. Developing head before booting, shown by cutting the stem. Photo: Tim McNee

## Floret development

This phase extends from the awn primordium stage until shortly after head emergence, when the stamens and **carpel** are fully mature and anthesis takes place.

There are three stages of floret development: the white, green and yellow anther stages. These are important to identify, because they indicate the fertility of each floret and whether a grain will be set. The three colours can be seen in the paddock when the floral structures are pulled apart.

### White anther stage

The anthers of each median floret grow quickly. They begin creamy white and translucent. The stamens are very short. The anther of each stamen is divided into four lobes. The carpel is very small and has hornlike outgrowths that become the styles.

### Green anther stage

When the stamens have grown to about 1 mm long they become bright green. The carpel grows rapidly and develops styles and the start of feathery **stigmas**.

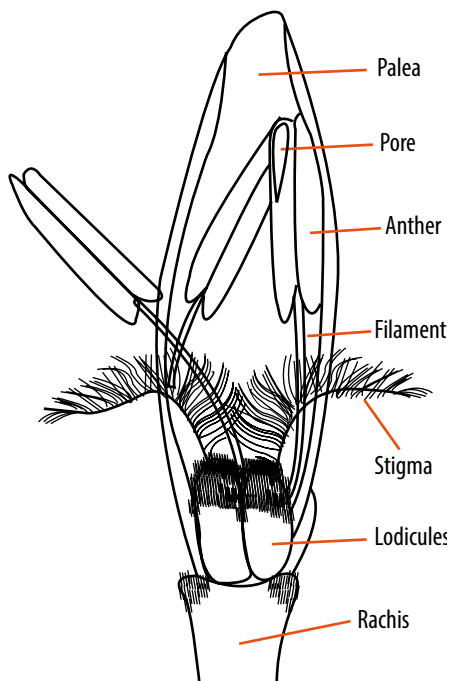


Figure 3–7. The median spikelet, showing the arrangement of the floral parts just before anthesis.

Source: Kirby and M Appleyard (1984)

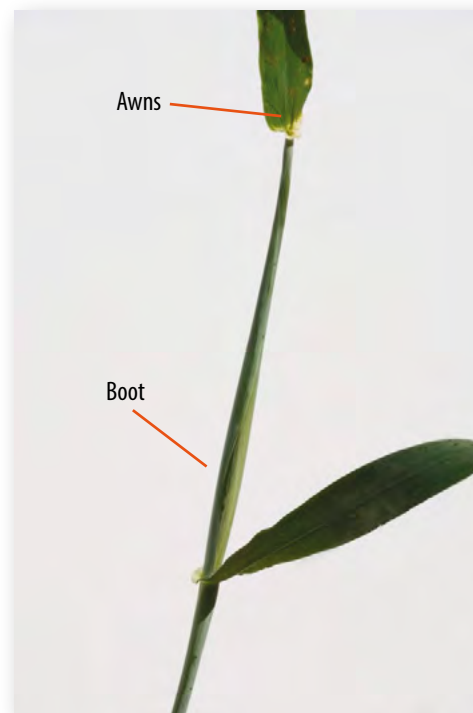
Reproductive cell division (meiosis) occurs in the anthers and carpel during the green anther stage, coinciding with booting. This stage is very sensitive to moisture, frost and heat stress. Stress at this point results in reduced floret numbers. Stress that interrupts female meiosis (cell division) can lead to sterility. Stress during male meiosis (cell division) can result in pollen sterility and reduced grain set.

### Yellow anther stage

In the yellow anther stage, the surviving florets are mature and anthesis is about to take place (Figure 3–7). The anthers swell and change colour from bright green through pale green to bright yellow. The changes in colour relate to pollen ripening. The carpel matures and the feathery stigmas are about to unfold to receive pollen.

## Booting and head emergence (Z41–Z60)

The ‘boot’ is formed by the sheath of the flag leaf. The rise of the head up the stem causes the flag leaf sheath to swell. This is the stage called booting (Figure 3–8).



### Carpel

The female part of the flower, consisting of the ovary, styles and three stigmas.

### Stigma

Structure at the tip of a carpel that receives the pollen.

### Lodicules

Structures below the ovary that swell up at flowering to expose the stamens and carpel.

Shortly after, the boot opens and the tips of the awns emerge from the tip of the flag leaf sheath. By this stage the ear has reached its full length.

The head becomes visible (Figure 3–9) and the process continues until the ear has completely emerged (Figure 3–10).



Figure 3–9. Head becomes visible (head peep) – Z51.  
Photo: Lowan Turton



Figure 3–10 Head emerges from the boot – Z60.  
Photo: Lowan Turton

## Anthesis (Z61–Z69)

Anthesis (flowering) is the bursting of the pollen sacs and fertilisation of the carpel. Anthesis is a short phase lasting only a few minutes in an individual floret, a couple of hours in a head and about 3 or 4 days across a dryland crop. The process usually occurs on a sunny day when the temperature rises above 11°C to 13°C. This can be at dawn, although it generally happens later in the morning.

Florets self-pollinate in 96% of cases. The pollen is shed before the flower opens. Barley pollen is small (35 to 45 µm) and light. Within 5 minutes of adhering to the stigma, the pollen grains take up moisture and germinate. One to two hours after pollination the pollen tube starts to grow. Pollen tube growth depends on temperature but generally takes 40 minutes. Fertilisation then takes place.

Anthesis can occur before complete head emergence, particularly under water stress.

There can be several days or weeks between the initiation of the first and last spikelets. Despite developing at different rates, the spikelets on each head flower close together. All the grains grow and ripen close together.

## Factors affecting reproductive development

Final grain yield is largely determined by grain number, which is set by tiller survival and fertile spikelet number and survival. There is a critical period 2 to 3 weeks before anthesis when water stress and/or high temperatures may greatly reduce floret production and survival. This is a period of rapid growth, creating competition for resources between the developing head and the elongating stem.

Spikelet survival is greatest when there are adequate water and nutrient supplies, optimum temperatures, and high solar radiation levels. Environmental stress between spikelet initiation and anthesis has the greatest impact on yield. This is the period when grain number is established.

## Moisture stress

Rapid growth is taking place during the reproductive phase, and the plant draws heavily on available moisture. When the water supply from the roots is slowed, the stomata in the leaves close to reduce water loss. This causes the leaves to heat up and reduces photosynthesis. This in turn reduces the amount of assimilates the plant is generating and has an impact on yield.

### *Moisture stress before anthesis*

Moisture stress before anthesis can reduce the number of fertile spikelets per head and in turn reduce potential grain number. The reduction is greatest when moisture stress occurs 10 days before head emergence (Z59). During this stage, stress decreases the number of spikelets, particularly at the tip of the head. Moisture stress at this stage can also advance the flowering time of all varieties.

The other effect of moisture stress is on pollen development, reducing the amount of pollen formed.

### *Moisture stress at anthesis*

The 10 days either side of anthesis are critical to final yield. Stress during this period will decrease seed set. A good water supply and a high leaf area index are essential to provide sufficient resources for the plant to set a high number of grains.

Moisture stress close to anthesis reduces the accumulation of water-soluble carbohydrates in the stem, meaning that there are fewer stored carbohydrates to transfer to the developing grain during grain fill. Rainfall just before anthesis will not undo the damage to potential yield from previous moisture stress.

## Temperature

During reproductive development, temperatures outside the optimum range of 5°C to 28°C affect photosynthesis and the development of reproductive parts. Matching the flowering date to the least stressful climatic period is a

way to minimise yield loss from frost or high temperatures. The aim is to have all crops flowering within the optimum temperature, and this is why varieties with different maturities need to be sown at different times. See *Flowering time* in this chapter.

### *Heat stress*

High temperatures are common during flowering and grain-filling and can be accompanied by moisture stress. Heat stress at this time has a significant influence on grain yield through a reduction in the number of grains.

As the temperature increases, the plant extracts more water from the soil and then evaporates it through the stomata to maintain leaf temperature. If the temperature becomes very high, and the transpiration rate becomes so rapid that more water is lost to evaporation than can be taken up by the roots, the plant closes its stomata to prevent wilting and reduce water loss. This decreases photosynthesis and transpiration, causing the leaf temperature to once again rise. Leaf photosynthesis begins to decline as the temperatures exceed 35°C, and at 45°C the photosynthesis rate is halved.

When the plant shuts down in this way, it reduces the flow of carbohydrates and other resources to the developing plant parts. Rapidly dividing cells, such as those in reproductive plant parts, need an uninterrupted supply of resources to prevent damage.

Pollen sterility and flower abortions are also common results of heat stress. Temperatures above 30°C during floret formation can cause complete sterility. During the 30 days before anthesis, the number of grains decreases by 4% for each degree increase in mean temperature above 14°C. There are fewer fertile heads or fewer grains per head.

### Cold and freezing

Frost damage can occur at all stages of crop development but is particularly damaging between flag leaf emergence and 10 days after anthesis. Frost damage is usually very patchy and is influenced by factors such as temperature, soil type and colour, soil moisture, cloud cover, wind speed, topography, crop species, crop nutrition and crop density.

Damage usually occurs when air temperatures at the height of the barley head fall below  $-3.5^{\circ}\text{C}$  on calm, clear nights. Damage increases as temperatures fall below this level. Damage also increases when plants are moisture stressed.

There is currently no genetic resistance to frost in commercial varieties, although some species are more susceptible than others. Research in NSW and Queensland suggests that the critical crop temperature for yield loss in barley is  $-4.0^{\circ}\text{C}$ . Barley can tolerate  $0.5^{\circ}\text{C}$  lower temperatures than wheat.

Air temperatures that fall to  $-4^{\circ}\text{C}$  or below can freeze stems or heads during stem elongation and booting. Partial freezing of the stem and the developing head distorts their growth; this effect is similar to those of hormonal herbicides, nutrient deficiencies, diseases, and moisture stress. Frost-affected stems display a ring of white tissue where the sap has frozen, or show blistering and cracking; this damage restricts the movement of resources to the developing head. Occasionally the head can get frosted in the stem, resulting in part or all of the head emerging white.

### Flowering time

It is critical to match variety and sowing date so that flowering occurs early enough to allow a long grain-filling period before the high evaporative demand and soil water deficit of early summer. The flowering period must also be late enough to minimise damage by frosts in early spring. Balanced with this is the need for a vegetative period long enough to support crop growth and the production of fertile florets, which determine yield potential.

To determine the optimum flowering time it is important to know the frost and heat risk for your area. Table 3–1 lists the 10% frost- and heat-risk dates at different locations in NSW. In the table,  $0^{\circ}\text{C}$  has been used to simulate a severe frost and  $2^{\circ}\text{C}$  to simulate a mild frost. (See also *Chapter 2: Factors affecting plant development – sowing time*).

The data in Table 3–1 are based on long-term weather records, but the risk of frost or heat stress varies from season to season.

Sowman® and Wheatman® are two decision-support computer programs that combine meteorological data and phenological field data to help determine the most appropriate sowing times for varieties on the basis of risk of frost and heat damage. Industry & Investment NSW's *Winter crop variety sowing guide* also provides a more generalised sowing window for different varieties, based on the same data. The Sowman® model for Condobolin run with an acceptable heat and frost risk of 1 year in 7. It has also been run to accept a potential yield of 70% or better on the basis of rainfall data for the site. Sowman® estimates the flowering

Table 3–1. Approximate dates when frost and heat risks are reduced to 10% at different locations in NSW

SITE	DATE WHEN THERE IS A 10% CHANCE OF SEVERE FROST ( $0^{\circ}\text{C}$ IN THE SCREEN*)	DATE WHEN THERE IS A 10% CHANCE OF MILD FROST ( $2^{\circ}\text{C}$ IN THE SCREEN)	DATE WHEN THERE IS A 10% CHANCE OF MILD HEAT STRESS ( $>30^{\circ}\text{C}$ IN THE SCREEN)
Moree	17 August	7 September	21 September
Dubbo	22 August	17 September	11 October
Cowra	25 August	11 October	27 October
West Wyalong	17 August	17 September	17 October
Hay	19 July	27 August	8 October

Source: Analysis of SILO data 1900 to 2006

\* The 'screen' is the Stevenson screen or instrument shelter used to protect meteorological instruments.



window to be between 8 September and 25 September (Figure 3–11).

It also needs to be taken into consideration that the time it takes a variety to reach maturity varies depending on where it is being grown and the season.

## Nutrition

### Nitrogen

As a general rule, applications of nitrogen from sowing to stem elongation increase yield, whereas applications after stem elongation increase protein. The later nitrogen is applied, the less time there is for it to be moved into the root uptake zone to be available to the plant:

- Nitrogen applied during early tillering (Z23–Z29) has the greatest impact on yield by increasing or maintaining tillers. Nitrogen applied at this stage is used almost as efficiently as that applied at pre-sowing. About 40% to 50% of the applied nitrogen is used by the plant.
- Application of nitrogen at stem elongation (Z30–Z40) increases yield by maintaining existing tillers and also slightly increases the protein level in the grain (up to 1%). About 30% of the applied nitrogen is used by the plant.
- Application of nitrogen at head emergence (Z51–Z59) has the maximum effect on grain protein. About 20% of the nitrogen applied is used by the plant.

Because of the cost and potential economic risks associated with nitrogen topdressing, it is best to carefully assess the agronomic state of the crop and the yield potential before applying nitrogen. Do not apply nitrogen to crops suffering stresses from drought, waterlogging, disease (foliar or root) or weed competition, as the crop will not respond to increased nitrogen and the applied nitrogen may be lost. It is also essential to assess how much nitrogen is presently available to the crop.

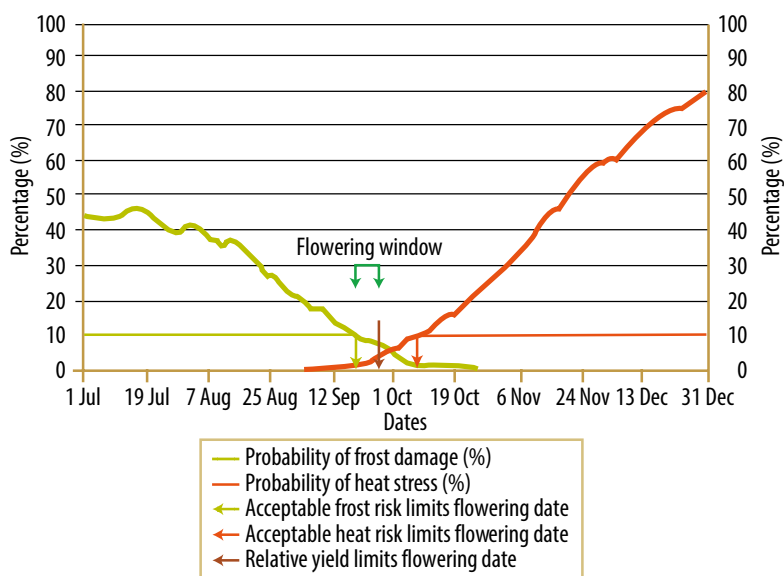


Figure 3–11. Theoretical flowering window at Condobolin. Based on 2°C frost risk and 30°C heat stress risk. Source: Sowman® decision-support system.

The difficulty of predicting rainfall events makes topdressing nitrogen as granular fertiliser (urea) risky in northern NSW. Split applications are more common in central and southern NSW.

For efficient recovery of urea nitrogen, moisture needs to move from the surface into the topsoil, carrying the nitrogen into the profile, where it makes contact with actively growing roots. A rainfall event of 5 mm or more is required soon after application.

## Herbicides

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 the type of herbicide, rate of application, growth stage of the crop and environmental conditions. Some pre-emergent herbicides can cause phytotoxicity to young seedlings as they grow through the band of treated soil, but damage is limited to reduced vigour and plants will recover before biomass or yield is affected. Some barley varieties are sensitive to selective grass herbicides (e.g. tralkoxydim), but the majority of problems are caused with weed control



with hormone weedicides in the late vegetative stage. These can cause yield reductions, as they affect the plant as it is going into the reproductive phase. Herbicide labels will warn of likely adverse effects on barley cultivars, so always check the label before use and follow the directions listed on the label.

### ***Late post-emergence weed control***

All herbicides can cause problems for crops if they are applied incorrectly. Certain hormone-based herbicides need to be applied at the correct time to avoid damage to the developing head and subsequent yield loss. Herbicides are grouped according to their mode of action, and these hormone herbicides belong to Group I. They are also often called phenoxy herbicides. (See Industry & Investment NSW *Weed control in winter crops*). Hormone herbicides are those that contain the following active ingredients: MCPA, MCPB, 2, 4-D, 2,4-DB, dicamba, picloram, triclopyr, clopyralid, or combinations of these and other herbicides.

Hormone herbicides function in a similar way to plant growth regulators. The herbicides interfere with a number of biological processes and protein synthesis, causing growth abnormalities. They move through the phloem or xylem and are quickly moved to areas of new plant growth, where they disrupt cell growth. In particular, they can stop pollen mother cells dividing and significantly reduce pollination of the crop.

Hormone herbicides also cause leaf distortion and rolling, reduced tiller numbers, sterility of florets or spikelets, abnormal head emergence, stunting and delayed heading, all of which affect yield.

The phenoxy herbicides 2,4-D and MCPA are commonly applied as late post-emergence treatments to reduce the seed set of wild radish, wild mustard, wild turnip and other weeds. These herbicides must be applied after Z30 and before booting and preferably no later than full flag-leaf emergence, otherwise serious yield losses may occur. Combinations of 2,4-D ester and metsulfuron methyl have caused large yield reductions and should not be used late in the season.

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.

When applying any chemical (and particularly these hormone herbicides) it is important to carefully observe the crop's growth stage and adhere to the recommendations on the label, in order to time the spray correctly and avoid potential yield loss. The time taken from it being safe to apply herbicide to the crop to change to it being unsafe can be as short as 6 days. Applying these herbicides under moisture stress may contribute to a reduction in yield.

There are usually four key stages to consider when timing herbicide application to avoid damage to reproductive parts. These are:

- between 3 and 5 leaf (maximum rates of MCPA Low Volume Ester [LVE])
- double ridging, which occurs at about the fourth to fifth leaf stage (Z14–15)
- stem elongation, which is also when the head is at 1 cm and the terminal spikelet has been formed. This indicates the end of tillering and the start of the reproductive phase (Z30).
- pollen formation, a particularly sensitive stage that usually occurs when the flag leaf is fully emerged at Z39, around 10 to 12 days before head emergence. The cut-off for 2,4-D and MCPA application is when the flag leaf is just visible (Z37). Depending on the herbicide, it may be too late when the awns are visible (Z51).

Detailed information on the timing of herbicide applications by crop growth stage can be found in Industry & Investment NSW annual publication, *Weed control in winter crops*.

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### ALWAYS READ THE LABEL

**Users of agricultural or veterinary chemical products must always read the label and any permit, before using the product, and strictly comply with the directions on the label and the conditions of any permit. Users are not absolved from compliance with the directions on the label or the conditions of the permit by reason of any statement made or not made in this publication.**

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## IN THE Paddock

The following are some examples of activities that can be done in the paddock to demonstrate the physiology discussed in this section. These are practical exercises to help farmers assess the progress of their crops at this stage.

### Identifying Z30 (the awn primordia stage)

*Aim: to accurately identify Z30.*

1. Carefully dig up a plant and identify the main stem and the tillers.
2. Remove the leaves on the stem.
3. Gently peel back the layers from the stem. This will expose the shoot apex.
4. Examine the head under the microscope and look at the components.
5. Dissect and examine a range of stages, particularly the head at 1 cm.
6. Try to observe spikelets and other parts of the head when it is very small.
7. Demonstrate or compare the effects on a crop where the stock have been pulled out too late. What has happened to the head?
8. Compare plants at different growth stages. For example, compare a plant that is not yet jointing and where the head is still below the crown with a plant where the head has elongated up the main tiller.
9. Discuss the impact of timing of stock removal on yield.

### Nitrogen topdressing

*Aim: to determine whether a yield response from nitrogen topdressing is likely.*

1. Count the number of tillers per m<sup>2</sup>, which gives an indication of potential yield (100 tillers/m<sup>2</sup>=1 t/ha).
2. In a 400 to 600 mm rainfall zone:
  - fewer than 500 shoots per m<sup>2</sup>, response likely
  - 500 to 700 shoots per m<sup>2</sup>, yield response unlikely
  - more than 700 shoots per m<sup>2</sup>, response likely.
3. Think about the impact of topdressing at each growth stage.

## IN THE Paddock

### Flowering

*Aim: to assess the stages of anthesis.*

1. Dissect a head into spikelets and florets and identify the reproductive parts.
2. Look at a number of stages to try to see the differences in reproductive development, such as the different anther colours.
3. Identify frosted heads, anthers, stigmas and ovaries. Compare frosted to healthy parts.
4. Identify parts of the paddock that may have advanced/delayed flowering, e.g. those with different topographies that make those patches more susceptible to frost.
5. Once these parts have been identified, discuss options like sowing time, variety, species and other agronomic factors.

### Modelling flowering time

*Aim: to use decision support systems to predict flowering date.*

1. Run through a Sowman® scenario.
2. Show how the different frost and temperature risks affect the flowering window.
3. Select variety and sowing time to match the window.

# 4. Grain development

by Tim McNee and Neil Fettell

## Chapter Snapshot

Grain development (Z71–Z90) – 58

*Cell division, Grain-filling (Z73–Z89),  
Physiological maturity (Z90)*

Factors affecting grain development – 60

*Moisture, Temperature, Nitrogen, Disease,  
Grazing*

Canopy management – 63

Measuring crop performance – 65

*Yield, Yield compensation, Grain quality,  
Harvest index, Water use efficiency*

References and further reading – 67

In the paddock – 69

*Estimating yield, Calculating harvest index,  
Calculating water use efficiency*

## Introduction

*Grain development is the period from fertilisation of the ovum to physiological maturity and is the final stage in the life cycle of the barley plant. Carbohydrates and protein are deposited in the grain as it grows and ripens.*

*Final grain yield is determined during this phase and is influenced not only by current conditions and management decisions, but by events that have preceded it. Grain quality is greatly affected by the conditions during grain development. In barley, grain quality is of particular importance, as malt barley is an important end-use product.*

*Chapter 4 explains how the grain develops and reaches physiological maturity, and gives details of the environmental conditions that influence its progression. In many cases these processes are similar to those observed in wheat.*

## Learning Outcomes

At the end of this chapter, you will be able to:

- describe the stages of grain development
- list the sources of carbohydrate for grain fill
- understand the impact of conditions during grain development on grain yield and quality
- identify the different components of yield, when they are set and what influences final yield
- estimate grain yield
- calculate harvest index
- calculate water use efficiency.



## Grain development (Z71–Z90)

Grain development is the period from fertilisation to physiological maturity when fertilised florets fill and ripen to form grain. Growth of the barley grain after fertilisation can be divided into two main stages: cell division and grain-filling.

### Cell division

Cell division commences at fertilisation and continues for approximately 14 to 30 days, depending on the genotype, environmental conditions, and position within the head. Given that final grain weight (an important yield and quality parameter) is closely related to endosperm cell number, any factor that influences cell division is of great importance. During cell division the endosperm volume increases rapidly. This increase is mainly a function of increasing cell number, rather than increased individual cell size.

### Grain-filling (Z73–Z89)

Grain-filling starts about 5 to 10 days after flowering and continues until the grain is ripe. Grain filling uses assimilates (amino acids and sugars), i.e. the products of photosynthesis. Starch is synthesised in the grain from these sugars while proteins are produced using amino acids.

This process coincides with a large increase in individual cell size. More than 80% of the increase in individual cell size occurs after the end of cell division.

The final weight of the grain is determined by the duration of grain fill and the rate of dry matter accumulation during this time. The rate and duration of grain-filling are influenced mainly by temperature, moisture and genetics. High temperatures are often associated with decreasing soil moisture contents during the grain-filling stage in Australian barley crops. This affects grain weight and grain quality.

### Sources of carbohydrate

There are two principal sources of carbohydrate during grain-filling. Under favourable conditions, the main source is current photosynthesis from green leaves, supplemented by photosynthesis by other plant structures, namely the stem, glumes and awns.

The other source is carbohydrate reserves that are stored, mainly in the stem, but also in the leaves, from photosynthesis before grain-filling. These reserves are stored in the form of water-soluble carbohydrates, particularly fructans. The contribution of water-soluble carbohydrates to final grain yield depends on environmental conditions during grain-filling. Their relative contribution is high when stress (e.g. high temperature, moisture, disease) limits current photosynthesis. Although there is some potential for plant breeders to select genotypes that are more efficient at providing stored water-soluble carbohydrates for grain-filling, there is nothing farmers can do to take advantage of this source of carbohydrate, apart from avoiding excessively high nitrogen conditions, which reduce water soluble carbohydrate storage.

Variation in environmental conditions change the relative contribution of different plant parts. Drought stress lowers the photosynthetic contribution of the leaves, so that other sources, such as stem reserves and head photosynthesis, increase in importance. The contribution of the leaves is also dependent on the length of time the canopy stays green.

### Sources of protein

Most of the nitrogen that is converted into protein is taken up before flowering, stored in the leaves and remobilised during grain fill. Nitrogen is an important component of chlorophyll and the enzymes involved in photosynthesis. As the plant develops, nitrogen is remobilised from older leaves (which then stop photosynthesising and senesce) and moved to younger growth, and eventually to the grain after flowering.

The plant can take up nitrogen after flowering, provided that the root system is healthy and the soil is moist. Whereas nitrogen applied early in the season will increase biomass and grain yield potential (provided that there is enough water), late application tends to mainly increase grain protein concentration.

## Physiological maturity (Z90)

Finally, the vascular system supplying the grain with water and nutrients is blocked and the grain stops growing and turns brown. This is physiological maturity. The mature barley grain comprises mainly starch (75% to 85%), protein (about 9% to 12%) and water (about 8% to 12%).

Physiological maturity occurs between 40 and 50 days after flowering. When maximum grain dry weight is achieved (Figure 4–1). In the field, the loss of green colour from the glumes and peduncle is an approximate indication of physiological maturity (Figure 4–2).

A sudden decline in grain moisture occurs after physiological maturity. At approximately 12% moisture the barley is ready for harvest. The current receival standards generally require delivered grain to have no more than 12.5% moisture (see Table 4–1). Storage of grain with a higher moisture content is undesirable.

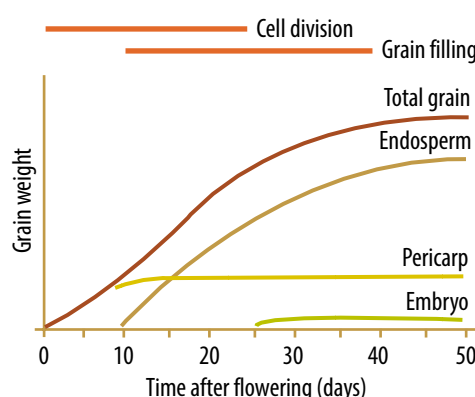


Figure 4–1. Dry matter accumulation during grain-fill.

Source: Modified from Savin and Molina-Cano (2002)



Figure 4–2. Mature barley heads.

Photo: Jan Edwards, Industry & Investment NSW

Table 4–1. Barley quality standards determined by Grain Trade Australia (GTA) [formerly the National Agricultural Commodities Marketing Association (NACMA)] and applying to individual loads

QUALITY	MALTING BARLEY NO. 1 SPECIFICATIONS	NSW FEED BARLEY NO. 1 SPECIFICATIONS
Grains	Must be two-row approved variety, with 95% varietal purity minimum, with a white aleurone layer of the current season and of sound, ripe, merchantable condition.	Must be two-row varieties with white aleurone layer.
Moisture	Not more than 12.5%. Regional variations may apply.	Not more than 12.5%.
Protein	Not more than 12% dry basis. Minimum 9.0% dry basis.	No limits.
Test weight	Not less than 65 kg/hL.	Not less than 62.5 kg/hL.
Retention (% by weight)	Above 2.5 mm Agtator screen. Min 70.0%	No limit.
Screenings (% by weight)	Below 2.2 mm Agtator screen. Max 7.0%	Max 15%
Germinative energy min. (%)	Not less than 95%.	No limit.
Germinative capacity min. (%)	Not less than 98%.	No limit.
Falling number min. (seconds) or RVA min. 130	300	
No limit.	No limit.	
Sprouted grains (count 100 grains)	Nil	Free from root system.
Skinings	Not more than 15% by count.	No limit.
Split/cleaved barley	1% by count.	No limit.
Black tip/pink or other cereal grains discoloured by field fungi	Not more than 10% by count in total. Field fungi by count Max 5%.	No limit.

Note: In addition to the above specifications, samples must meet Weed Seeds and other Foreign Seeds and Objectionable Matter standards.

Source: Industry & Investment NSW (2009).

## Factors affecting grain development

In Australia, grain-filling occurs as temperatures increase. The temperature increase is usually compounded by decreasing soil moisture levels. These environmental conditions affect the rate and duration of grain fill, influencing grain size and protein content and quality.

### Moisture

Adequate soil moisture is essential during grain-filling for transpiration and photosynthesis.

Crops with high levels of pre-flowering biomass use a lot of soil moisture and are at increased risk of running out of water during grain fill. This commonly results in small, light grains. Such grains are more likely to have a high protein level, which is undesirable for malting purposes. The impact of moisture stress on grain size depends not only on stress severity but also timing: in particular, timing in relation to flowering (Figure 4–3). Water stress in the period before flowering can have variable effects on grain size, depending on how this stress affects grain number per unit area. The later the stress is imposed after flowering the smaller the impact on grain size.

- Absence of water stress during the grain-filling period increased grain weight.

Figure 4–3. Influence of water stress on grain growth and dry weight. Water stress treatments were applied 22, 10 or 4 days before flowering or 14 days after flowering.

Source: Modified from Aspinall (1965)

### Moisture stress

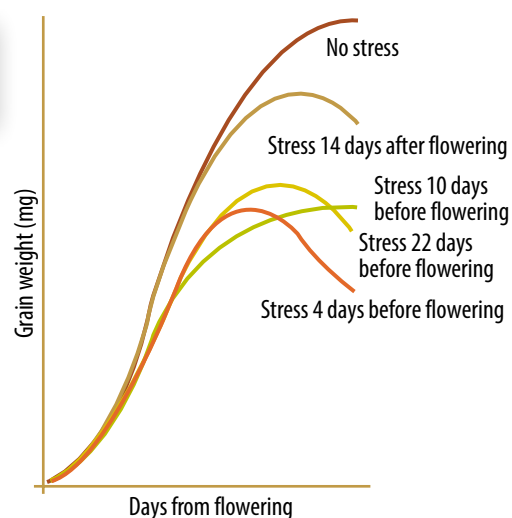
Moisture stress reduces the photosynthetic capacity of the crop by causing the premature death of leaves, thus reducing the length of the period in which carbohydrate can be transferred to the grain. The rate of starch synthesis in the grain also falls during moisture stress.

### Pre-harvest sprouting

Along with many other commercial crop species, barley has lost much of its dormancy as it has become domesticated. Malting barleys, in particular, have very little dormancy. This makes them susceptible to germinating before harvest. This process is known as pre-harvest sprouting. Pre-harvest sprouting reduces seed viability and lowers grain quality.

Pre-harvest sprouting results from rainfall and high humidity after physiological maturity. It requires the seed to be wet for 20 to 30 hours. This increases the seed moisture content. Once the moisture content reaches 40% to 50% the seed begins the germination process. Enzymes including alpha amylase begin breaking the starch and protein in the grain into sugars and amino acids. If this continues, the seed can sprout in the head.

If the moisture content has not reached 40%, wind can dry the seed and stop it sprouting. However, some damage may have occurred to the endosperm. It may show reduced viability, its falling number



(a measure of starch damage) may be high, and it may not make malting grade.

## Temperature

Grain development is very sensitive to temperature, which affects:

- grain weight
- the source of carbohydrate
- the quality of the protein.

Grain weight is determined by the rate and duration of grain-filling. Both processes are driven by temperature. As temperatures increase, the duration of dry matter accumulation decreases. Under optimum conditions ( $<15^{\circ}\text{C}$ ) this decrease (due to rising temperatures) is cancelled out by an increase in grain-filling rate, resulting in no reduction in the final grain weight or yield.

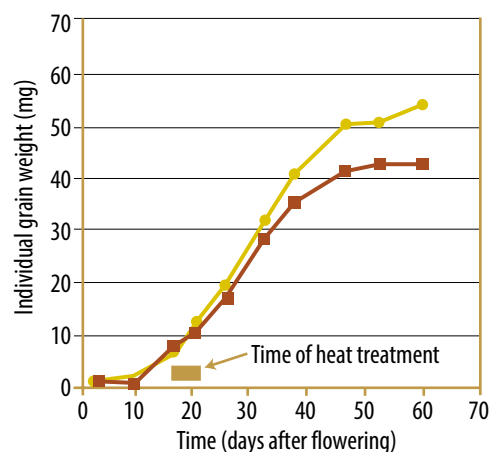
As temperatures rise above  $15^{\circ}\text{C}$  the grain-filling rate is unable to increase sufficiently to offset the reduced grain-filling duration. This is a manifestation of heat stress. The result is reduced starch synthesis, a reduction in grain weight and higher protein levels.

If the temperature rises above  $30^{\circ}\text{C}$  to  $35^{\circ}\text{C}$ , stress increases and the plant can experience heat shock. Both the rate and the duration of grain-filling decrease. The effects of heat shock are not cumulative. The maximum temperature determines the extent of the damage, not the length of time the temperature remains over  $30^{\circ}\text{C}$  to  $35^{\circ}\text{C}$ . Once there has been a heat shock event any subsequent events have less effect on yield than the initial heat shock event. If cool temperatures follow, yield losses cannot be reversed. Like heat stress, heat shock reduces individual grain weight (Figure 4–4).

Heat stress or short periods of heat shock during grain-filling are common in Australia. To minimise the risk, it is critical to time sowing so that flowering and grain-filling occur before high temperatures set in. In western cropping areas, where the grain-filling period is more prone to high temperatures and low soil moisture, it will be difficult to achieve malting status.

## Nitrogen

Nitrogen is an essential component of protein, and its availability during grain-filling is important in determining final yield and quality.



- Heat stress decreased individual grain weight.
- Grain growth was mainly affected after, as opposed to during, heat stress.

Figure 4–4. Change in individual grain weight with time after flowering under control (yellow) and heat (brown) treatments in Schooner barley. Box shows time of heat treatment. Heat treatment was  $40^{\circ}\text{C}$  for 6 hours a day for 5 days.

Source: Modified from Savin et al. (1996)

Late nitrogen applications are not often used in dryland malting barley production. Unlike in wheat, where high protein levels are desirable, malt-quality barley requires protein levels of 9% to 12%. Under irrigated conditions there may be situations where late nitrogen application may be warranted if grain protein is likely to fall below the minimum requirement for receival as malt.

Once the amount of nitrogen applied is sufficient to maximise yield, further nitrogen no longer increases starch levels but continues to increase the protein content of the grain (Figure 4–5).

By flowering time, potential yield is set, so that nitrogen applied after flowering is converted to amino acids and translocated to the grain, where it is converted into protein, increasing the grain protein concentration.

A hot, dry grain-filling period can result in relatively high protein percentage, even if only modest levels of nitrogen have been applied. This occurs because the adverse conditions tend to reduce starch synthesis more than they do protein (see Figure 4–6).

Crops with high nitrogen levels have an increased risk of haying-off, producing very high levels of biomass early in the season. The increased biomass draws heavily on the products of photosynthesis, which are used to build the additional tillers and leaves, leaving very little to

store as water-soluble carbohydrates for translocation during grain fill. If moisture stress occurs, the grain is unable to be filled adequately.

## Disease

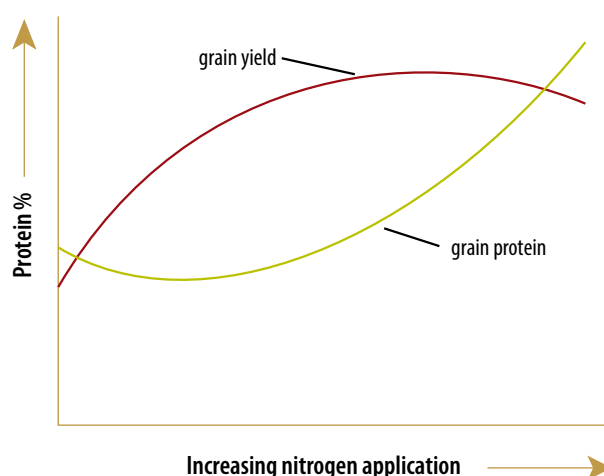
Disease may reduce both the canopy size and the duration of green leaf. The crop then depends more on stored reserves to complete grain fill. Generally this leads to lower yields through reduced grain weight.

Some foliar diseases simply reduce the leaf area available for photosynthesis, with a proportional loss in yield. Root and crown diseases limit the plant's ability to take up water, intensifying the impact of moisture stress and decreasing photosynthesis. This usually results in reduced average grain weight.

Disease also causes the plant to divert resources to the disease sites to fight infection, reducing the supply of resources to the grain.

## Grazing

The impact of grazing on yield is highly variable and depends on many factors, including the growth stage, the timing of stock removal, the duration of grazing, and seasonal conditions.



- Once the amount of nitrogen applied is enough for maximum yield, additional nitrogen increases the protein percentage.

Figure 4–5. Relationship between nitrogen application, grain yield and grain protein percentage.  
Source: Anderson and Garlinge (2000).

Grazing reduces the leaf area at flowering; this lowers photosynthesis rates during grain-filling and reduces the storage of reserves. Grazing does not alter the ability of the plant to draw on stored reserves, but it does reduce the amount available. Stored reserves can be completely exhausted by maturity in crops that have been grazed. However, because there are fewer stored reserves, photosynthesis during grain-filling makes a greater contribution to final yield.

Grazing also delays flowering in spring types; this can shorten the duration of grain fill and may cause grain fill to occur in higher temperatures with lower moisture availability. In crops sown too early delayed flowering may be an advantage.

The duration of grazing is one of the most significant factors in determining the impact on grain yield. The latest time and severity of grazing of crops should be governed by the position of the immature head in the stem. Stock should be removed before the Z30 growth stage.

The use of barley varieties with a cold requirement (vernalisation) for initiation of heading is one method of extending the grazing window when sowing early. Unfortunately, not many current barley varieties have strong cold requirements for heading. Urambie is an exception and could be considered when sowing early for grazing and grain recovery.

## Canopy management

The aim of canopy management is to maintain the size and duration of green leaf to maximise photosynthesis during grain fill. The canopy needs to stay green and photosynthesising until the mid-dough stage, when the grain starts to dry down.

To maximise yield potential, a balance is needed between the canopy, which is photosynthesising and producing assimilates, and the head, which uses the assimilates to fill its grain. If the canopy becomes too big it competes with the growing heads for resources, especially during the critical 30-day period before

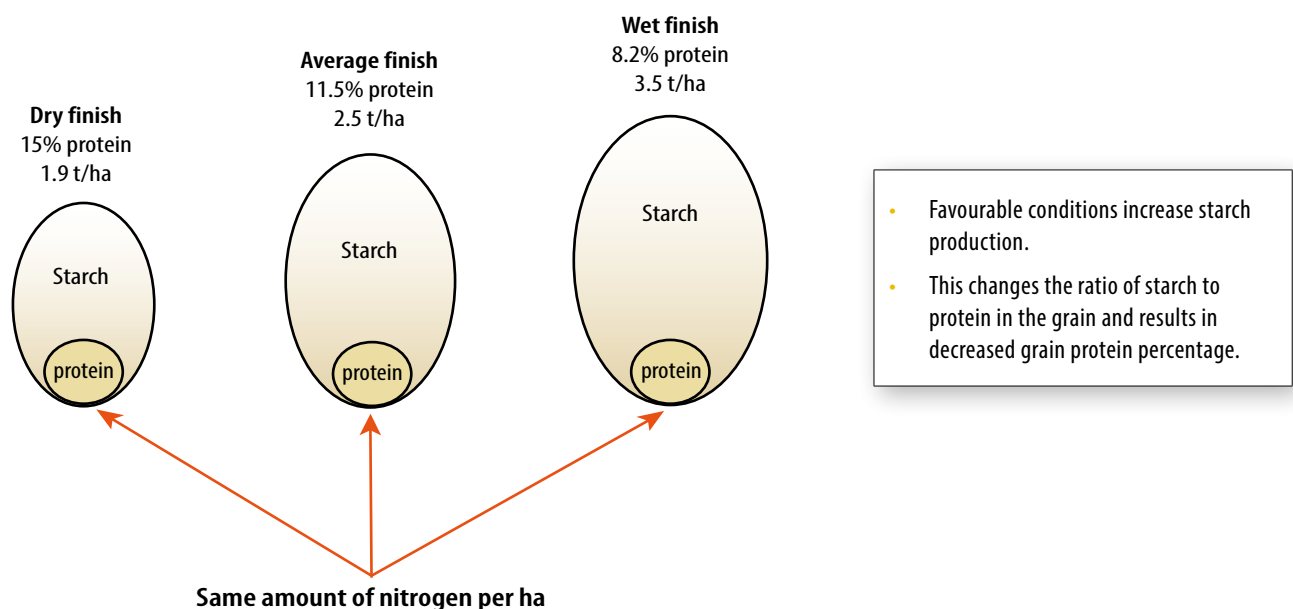


Figure 4–6. Different seasonal finishes affect the ratio of starch to protein in the grain and therefore the percentage of protein. Source: NSW DPI (2008)



flowering (Figure 4–7). This period is important, as it is when the main yield component (grain number per unit area) is set. Increased competition from the canopy with the head may reduce yield by reducing the number of grains that survive for grain fill.

After flowering, temperature and evaporative demand increase rapidly. If there is not enough soil moisture, the canopy dies faster than the grain develops, leading to the production of small grain.

Excessive nitrogen and high seeding rates are the main causes of excessive vegetative production. Unfortunately, optimum nitrogen and seeding rates are very seasonally dependent. Under drought conditions, nitrogen and seeding rates regarded as inadequately low under normal conditions may maximise yield, whereas higher input rates may result in progressively lower yields. Alternatively, in wetter than normal years, yield may be compromised with normal input rates.

The extreme of this excessive early growth scenario is ‘haying-off’, where a large amount of biomass is produced, using a lot of water and resources. Later in the season, there is not enough moisture

to keep the canopy photosynthesising, and not enough stored water-soluble carbohydrates to fill the grain. As a consequence, grain size and yield decrease.

To attain maximum yield, it is important to achieve a balance between biomass and resources. The main factors that can be managed are:

- plant population and arrangement (row spacing)
- nitrogen
- sowing date
- weed, pest and disease control.

Of these inputs, nitrogen, row spacing and plant population are the most important to canopy management. Excessive amounts of nitrogen and high plant density can result in greater early growth, leaving less water for the grain-filling period. This may result in lower grain retention (an important quality parameter), as nitrogen (Figure 4–8) or seeding (Figure 4–9) rates are increased.

- High-biomass crops, with pinched grain from lack of moisture during grain fill, lie to the right of the maximum yield line and have a low harvest index.
- Crops that have low biomass and are not able to set enough grain for high yield but have enough moisture for grain fill are on the left of the maximum yield line. These crops have a high harvest index.

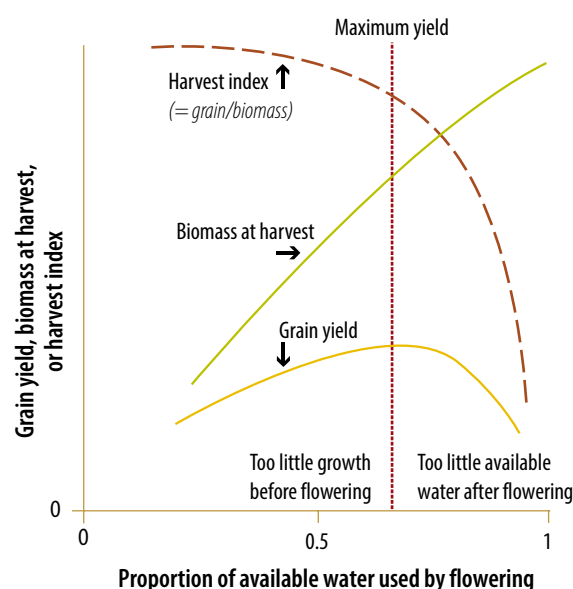


Figure 4–7. The proportion of available water supply used by flowering in dryland crops has a large influence on the yield of the crop, depending on the dry matter at harvest. Source: Passioura (2002)

## Measuring crop performance

### Yield

There are two main components of yield:

- number of grains per unit area
- average grain weight.

Grain number is set at about flowering time, with average grain weight being set afterwards. Recent improvements in barley yield have come about as a result of increases in grain number rather than increased average grain weight.

Given the importance of grain number to yield it is important to prevent unnecessary stress on the crop prior to flowering. The importance of grain number to yield also means that an approximation of yield can be made during the grain filling period (See *In the paddock: estimating yield*).

### Number of heads

Head number is the first yield component and is set by tiller number/m<sup>2</sup>. Tiller number depends on initial plant population, the variety, and the environmental conditions (particularly nutrition). In most barley crops, the plant produces more tillers than will survive to produce heads. Stress and competition for nutrients cause tiller death.

### Weight per grain

The weight per grain is commonly expressed as 1000-grain weight. Factors that affect the 1000-grain weight include:

- variety
- nitrogen
- plant density
- post-flowering environmental conditions
- grain position within the head
- root and foliar diseases.

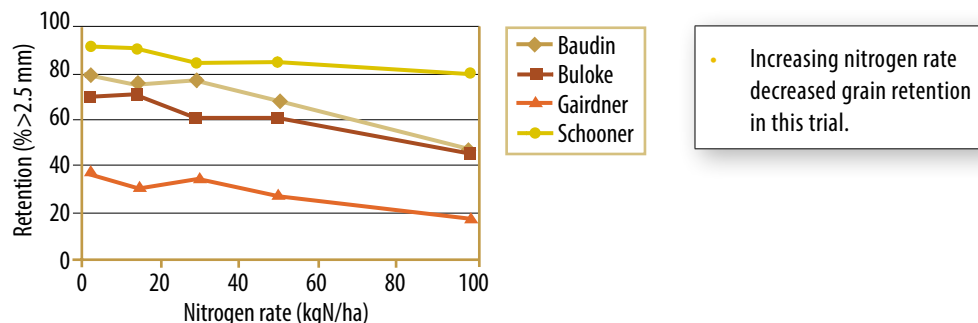


Figure 4–8. Influence of applied nitrogen on barley grain retention. Source: Fettell et al. (2006)

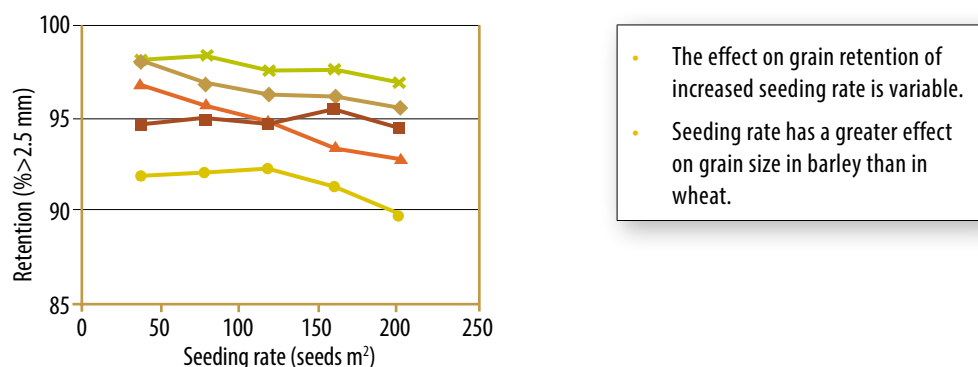


Figure 4–9. Influence of seeding rate on barley grain retention. Source: Fettell et al. (2006)

Some genotypes have inherently larger seed because of higher rates of dry matter accumulation during the grain-filling period.

Grains from the top of the head or from later-formed tillers are generally smaller than grains lower in the head and from earlier-formed tillers.

### Yield compensation

A barley crop responds to improving or deteriorating conditions throughout the season. The ability to compensate means a crop can produce yield even when one or more of the yield components is affected by environmental conditions. However, maximum yield is more likely when yield components are balanced.

As the season progresses there is less time to adjust. In particular, flowering marks an important stage. Shortly after flowering, head number and grain number (per unit area) are set. The only component left is average grain weight. However, barley grain yield is more related to grain number than it is to average grain weight. So the barley crop has a limited ability to respond to improving conditions after flowering.

Rainfall after flowering will increase grain size and can reduce the protein percentage, which may be beneficial, especially in drier cropping areas where small grains and high protein levels reduce the likelihood of achieving malt-quality barley.

### Grain quality

Grain quality is as important in barley as it is in wheat. Barley grain is used mainly for brewing and stockfeed. In contrast to the stockfeed market, there are much more stringent quality criteria that must be met to achieve malt quality barley. Variety, protein percentage, grain size (retention and screenings) and moisture are the main criteria assessed at receipt. Other criteria include test weight, germination, falling number (a measure of starch quality), number of sprouted grains, split grain percentage and fungal activity. There are fewer specifications for feed grain and more latitude within such criteria (see Table 4–1).

Barley that has high protein and/or small grain size, or grain that is weather damaged, is usually classified as 'feed' barley. A variety without malt classification also has to be delivered into the feed market, irrespective of its quality characteristics.

The protein concentration of barley is expressed as a percentage. It is the ratio of carbohydrate to protein in the grain. Protein percentage usually varies from 8% to 15%, but can be as high as 20% in a drought year. Very high or low protein levels can affect the malting and brewing process. High protein increases results in lower malt extract, steeping time, and can reduce a beer's shelf life. Low protein inhibits fermentation and can reduce the stability of the beer foam.

Small grain can affect malting through slower germination and different steeping requirements. Smaller grain also has less starch and consequently less malt extract. Lower starch levels also make smaller grain less desirable for stockfeed purposes. Anything that reduces photosynthetic area (e.g. foliar disease, insects, hail) or impedes water uptake (e.g. root or crown disease) will reduce grain size.

### Harvest index

The harvest index is a measure of the proportion of above-ground biomass that is grain. Newer, higher yielding varieties have increased harvest index rather than plant biomass. As in wheat, increased harvest index has come primarily from increasing the number of grains per unit area as opposed to increasing average grain weight. Estimating harvest index can provide an indication of how effectively a crop has utilised available resources (See *In the Paddock: Calculating harvest index*).

## Water use efficiency

Water use efficiency is a measure of how efficiently crops have used available moisture. It is defined as grain yield divided by the water available to the crop. (See *In the Paddock: Calculating water use efficiency*.) A low water use efficiency may mean that there has been a problem (e.g. with disease, nutrition, subsoil constraints or climate) that has prevented the crop from reaching its water-limited potential.

There are many assumptions when calculating water use efficiency. For example, adequate nutrition and weed control are required for crops to use water efficiently. Having said this, the calculation of water use efficiency allows the barley grower the opportunity to assess how efficiently they are utilising one of their most limiting factors.

The water use efficiency achieved varies from season to season, as the timing of rainfall has a large impact. Rainfall just before or after flowering is used more efficiently than rain at other growth stages. The size of the fall is also important. One 20 mm fall is likely to have less soil evaporation than five falls of 4 mm over several weeks. The amount of water lost to soil evaporation is higher in areas where in-crop rainfall is more frequent and is less where crops depend more on stored moisture.

Software packages such as Yield Prophet® are now available for doing these calculations, taking into account seasonal conditions.

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## IN THE Paddock

The following are some examples of what can be done in the paddock to demonstrate the physiology discussed in this section. These are practical exercises to help farmers assess the progress of their crops at this stage.

### Estimating yield

*Aim: to estimate yield in the paddock.*

1. Count the number of heads per 1.0 m row at five to 10 locations within the paddock. Use more locations in paddocks with greater variation.
2. Count the number of grains per head in 10 to 15 heads. Count a range of head sizes (i.e. main and later tillers) to get an accurate estimate.
3. Choose an estimate of seed weight between 0.025 and 0.035 g. Seed weights can vary considerably between seasons. Hot, dry post-anthesis conditions or disease can reduce grain size. This is especially so when a large grain number per unit area is set at anthesis and followed by poor grain-filling conditions.

$$\text{Yield (t/ha)} = \frac{\text{heads/m row} \times \text{number of grains/head} \times \text{estimated seed weight (g)}}{\text{row space (cm)}}$$

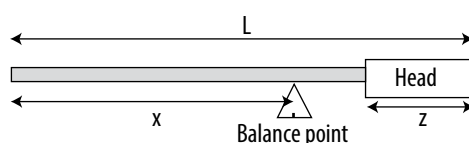
COUNT	NUMBER OF HEADS/M <sup>2</sup>	NUMBER OF GRAINS PER HEAD	ESTIMATE OF GRAIN WEIGHT (g/grain)	YIELD (t/ha)
Example (25 cm row space)	25	25	0.025	0.625
Example (25 cm row space)	45	45	0.025	2.025
Example (25 cm row space)	25	45	0.035	1.575
Example (25 cm row space)	45	35	0.035	2.205
1				
2				
3				
4				
5				
Average				

### Calculating harvest index

*Aim: to calculate harvest index using a method described in Farming Ahead and developed by Anthony Van Herwaarden of CSIRO.*

1. Cut several small sheafs of barley at ground level around a paddock and place a couple of rubber bands around each sheaf to hold it together.
2. Measure the height to the top of the average head (excluding awns) (L) and the length of the average head (Z), both in centimetres.
3. Place the sheaf over the edge of a table or other sharp edge and measure the distance from the base of the stems to the point at which the sheaf just balances (X).
4. The harvest index is calculated using the formula:

$$\text{Harvest index} = \frac{(2X - \text{height to the top of the average head})}{(\text{height to the top of the average head} - \text{length of the average head})}$$





## IN THE Paddock

### Calculating water use efficiency

*Aim: to use rainfall records to estimate the water-use efficiency (WUE) of a crop.*

1. Using your rainfall records, calculate the amount of water that was available to the crop.  
The formula is:  
Total available water (mm) = 25% of fallow rainfall + in-crop rainfall (1 May to 30 October)
2. It is assumed that 25% of the rainfall during the fallow will be stored in the soil and available to the crop. This varies depending on stubble cover, weed growth and the rainfall pattern.
3. Using the total water supply and the yield, calculate water use efficiency (WUE).
4. Subtract 110 mm from the total available water to account for the water required by the crop to grow and for losses from run-off and evaporation.

The WUE is calculated using the following formula:

$$\text{WUE (kg/mm/ha)} = \frac{\text{crop yield (kg/ha)}}{\text{total available water (mm)} - 110 \text{ mm}}$$

WUE (kg/mm/ha)			
	Paddock 1	Paddock 2	Paddock 3
Fallow rainfall			
In-crop rainfall			
Total water supply			
Yield (t/ha)			
WUE			

# Glossary

## *Aleurone*

The outermost cell layer of the endosperm, usually only one cell thick and the only endosperm tissue alive at maturity. The cells of this layer synthesise enzymes needed at germination.

## *Anther*

The terminal part of a stamen, producing pollen, in pollen sacs.

## *Anthesis*

Flowering; the moment when pollen is released from the anthers.

## *Apex*

The tip of an organ.

## *Apical meristem*

Growing point; a zone of cell division at the tip of the stem or root.

## *Auricles*

Small hairy projections that extend from the leaf collar.

## *Axil*

The angle where the leaf joins the stem.

## *Boot*

Sheath of the uppermost leaf, enclosing the head.

## *Bract*

A modified leaf, or leaf-like structure.

## *Carpel*

The female part of the flower. A carpel consists of three parts: the ovary, which becomes the seed after fertilisation; styles, extensions of the ovary; and stigmas, specialised filaments on which the pollen falls and germinates.

## *Dormancy*

A resting period in the life of a plant when growth slows or appears to stop. In cereals this is between the start of seed dry-down and maturity.

## *Dorsal*

On or near the back; the side of the organ away from the central axis.

## *Double ridge*

Marks the transition from the 'vegetative' to the 'floral' state in the shoot apex. Growth of the leaf ridge stops and the floral ridge begins to grow, giving a 'double ridge' appearance to the shoot apex. The plant no longer produces leaves and develops only flower parts.

## *Early milk*

A description of the grain in early development; when punctured the grain contents are starting to appear milky.

## *Embryo*

Part of the seed that contains the main plant structures. It is made up of the scutellum, plumule and radicle.

## *Endosperm*

A nutritive tissue within the seed that surrounds the embryo and provides energy for germination.

## *Fertilisation*

The union of male and female reproductive cells during the process of sexual reproduction.

## *Filament*

The stalk of a stamen.

## *Flag leaf*

The uppermost leaf on the stem.

## *Floret*

The barley flower.

## *Glume*

A strong protective bract on the outside of the spikelet, at the base of the barley head.

## *Hard dough*

A description of the grain at maximum dry weight. The grain is hard to puncture and has started to dry off.

## *Harvest ripe / Harvest maturity*

The grain has dried off and is ready to be harvested. It has a moisture content of <14%.

## *Husk*

The outer protective covering of the seed.

## *Imbibe*

To absorb water.

## *Internode*

The part of a plant stem between two nodes.

## *Leaf collar*

The point where the leaf sheath joins the leaf blade; it has two features: the ligule and auricles.

## *Lemma*

The lower of two bracts that protect the floret.

**Ligule**

Thin colourless membrane around the base of the leaf collar.

**Lodging**

Term used when the crop canopy lies over or leans towards the horizontal from heavy rain and wind.

**Lodicules**

Two small structures below the ovary that swell up at flowering, forcing open the enclosing bracts, exposing the stamens and carpel.

**Medium milk / mid dough stage**

A description of the half-grown grain. When the grain is punctured the contents are milky.

**Mesocotyl**

That part of the young plant that lies between the seed (which remains buried) and the plumule.

**Meristem**

Growing point where active cell division takes place and permanent tissue is formed.

**Meristematic tissue**

A specialized plant tissue characterized by cell division and growth.

**Node**

The part of a plant where one or more leaves grow. The nodes are separated on the stem by the internodes.

**Ovule**

The part of the plant that, after fertilisation, develops into the seed.

**Palea**

The upper of two bracts enclosing the floret.

**Peduncle**

The final internode of the plant stem that bears the head (ear).

**Plumule**

Growing point of the seed that develops into the shoot bearing the first true leaves.

**Pollen**

The male gametes, which are held in the anthers.

**Pollination**

The transfer of pollen from an anther (the male reproductive organ) to a stigma (the receptive part of the female reproductive organ).

**Primordia**

Organs in their earliest stage of development.

**Physiological grain maturity**

The grain is fully developed and the moisture content is less than 40%.

**Rachis**

The primary axis of the barley head; it bears the spikelets.

**Radicle**

The part of a plant embryo that develops into the primary root.

**Scutellum**

A shield-shaped structure in a seed that absorbs the soluble sugars from the breakdown of starch in the endosperm.

**Shoot apex**

See apical meristem.

**Soft dough**

Grain at maximum fresh weight. When the grain is punctured the contents are still wet but starting to become floury.

**Spikelet**

Part of the head consisting of florets on a thin axis, the rachilla.

**Stamen**

The structure in a flower that produces pollen grains, consisting of a stalk (filament) and an anther.

**Stigma**

The glandular sticky surface at the tip of the carpel of a flower, which receives the pollen.

**Tiller**

A lateral shoot that develops from the axillary bud of leaves at the base of the main stem.

**Water ripe**

A newly pollinated grain. When the grain is punctured its contents are very watery.





Industry &  
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