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MAIZE

Growth & Development

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

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

PROCROP
Profitable, sustainable cropping

NSW DEPARTMENT OF
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Maize growth & development

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Produced by NSW Department of Primary Industries, March 2009

ISBN 978 0 7347 1955 3

8603

Acknowledgments

This book is part of the PROCROP series, a project funded by the Natural Heritage Trust.

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Other contributions and assistance

We acknowledge Andrew Schipp, District Agronomist, Hay, for his contribution to the Introduction.

We would like to thank our expert reviewers:
Steve Wilson, Corn Research Manager, Pioneer Hi-Bred Australia
Rob McCarron, Corn and Sunflower Business Manager, Pacific Seeds
Paul Newell, Corn Breeder, Pacific Seeds
Don McCaffery, Technical Specialist, NSW DPI

We would also like to thank the Iowa State University for permission to reprint material from their Special Report 48 *How a corn plant grows.*

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Contents

Preface

This book describes the growth and development of the maize plant from germination to kernel filling. It also provides the environmental factors that influence each growth stage and the management actions to optimise yields.

The aim of *Maize growth and development* is to link plant physiology and crop management decisions. It will help agronomists and farmers to understand the life cycle of the maize plant and the factors that influence growth and development, and to identify the different 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 maize plant, and its growth and management. Included in each chapter are practical exercises to show how knowledge of plant physiology can be applied in the paddock.

Introduction

by Kieran O'Keefe and Andrew Schipp

Growing maize

Maize is the third most important cereal crop species in the world (after wheat and rice) and is grown across a wide range of climates, but mainly in the warmer temperate regions and humid subtropics. Maize has multiple uses, including for human foods, animal feeds, and the manufacture of pharmaceutical and industrial products. It is the staple food source for people in many countries. As an animal feed it is highly desirable because of the high energy and feed value of the kernel, leaf and stem. It is becoming increasingly important in many countries for industrial and pharmaceutical applications. It can be used to produce starch, ethanol and plastics and as a base for antibiotic production. Over the past 40 years the total global area sown to maize has increased by about 40%, and production has doubled.

Maize is a C_4 (tropical) plant. Compared with C_3 (temperate) crops, maize uses carbon dioxide, solar radiation, water and nitrogen more efficiently during photosynthesis. The water-use efficiency of maize is approximately double that of C_3 crops grown at the same sites. The transpiration ratio of maize (molecules of water lost per molecule of carbon dioxide fixed) is 388, whereas that of wheat is 613 and soybean 704.

New South Wales production

Temperature and available moisture determine where maize is grown in NSW (Figure i). Production areas include the North Coast, Liverpool Plains, Northwest Slopes and Plains and that of Southern Irrigation districts. In these areas the crop grows best in deep, well drained, fertile soils.

Before the recent drought began in 2002, most maize in NSW was grown in the Riverina region of south-west NSW under full irrigation. Irrigated maize in the Riverina region usually requires between 600 and 1000 mm of irrigation water per hectare (6–10 ML/ha) to produce a high-yielding grain crop. The irrigation requirement is determined by the choice of variety, the soil water-holding capacity, irrigation efficiency, evaporation and in-crop rainfall.

Maize is also grown as a dryland crop in the northern parts of the State where there is more reliable summer rainfall, which gives adequate soil moisture at planting time. Some of these crops may receive supplementary irrigation.

C_3 plant
Has a normal type of photosynthesis: carbon dioxide is first incorporated into a 3-carbon compound. Most plants are C_3 plants. Examples of C_3 plants are wheat, barley and oats.

C_4 plant
Has a specialised type of photosynthesis: carbon dioxide is first incorporated into a 4-carbon compound. C_4 plants carry out photosynthesis faster than C_3 plants under high light intensity and high temperatures. This gives better water use efficiency compared with that of C_3 plants at the same location, because the stomata (pores) are open for a shorter period of time.

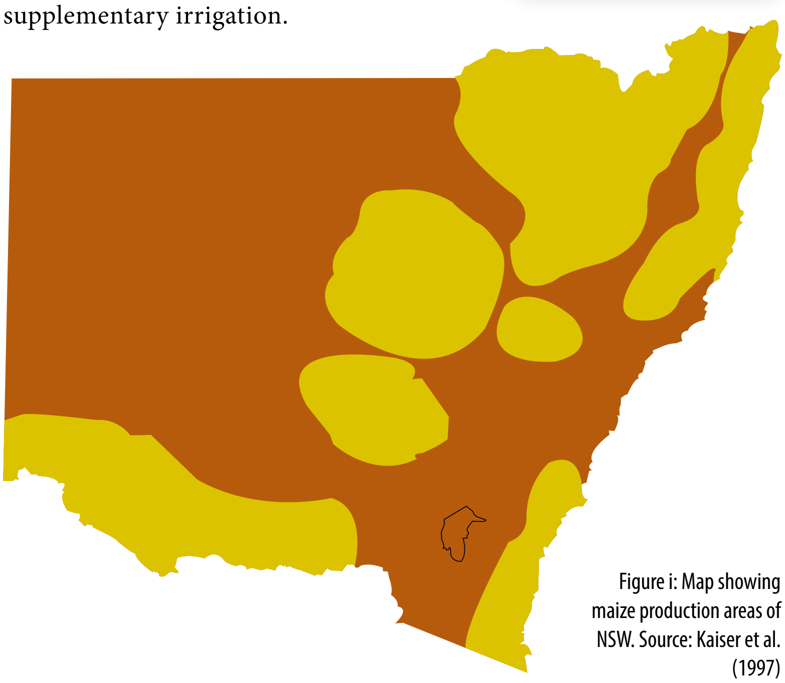


Figure i: Map showing maize production areas of NSW. Source: Kaiser et al. (1997)

Allele
One member of a pair of genes

There are two main types of starch contained in maize kernels. Regular maize contains approximately 73% amylopectin starch and 27% amylose starch.
Waxy maize produces 100% amylopectin starch. High-amylose maize can be 80% to 90% amylose starch and 10% to 20% amylopectin starch.

Amylopectin
A glucose polymer that is a component of starch and has a branched structure.

Amylose
A glucose polymer that is a component of starch and has a linear structure. This type of starch is known as resistant starch and is used as a food additive to help reduce the risk of bowel cancer.

The average area of maize grown in NSW from 1998 to 2007 was 26,944 ha, producing 211,681 tonnes of grain (Figure ii).

Maize types

Almost all maize in NSW is produced from hybrids.

A hybrid is a cross between strains within a single species. In commercial hybrid maize, these strains are fixed inbred lines. Hybrids are produced and selected because they have desirable characteristics that are greater than those of the individual parents.

The cross between two different inbred lines produces an F1 hybrid (Figure iii). This hybrid has two alleles, one contributed by each parent. One is usually dominant and the other recessive. The F1 generation produces offspring that are all similar.

Hybrids are similar in growth and development, but they vary widely in agronomic characteristics and end-use quality. When selecting a hybrid it is important to consider the potential end-use, relative maturity yield potential and disease resistance.

The end-uses of maize grain are processing (human consumption or industrial purposes) and stockfeed. Maize is also grown for silage.

Maize for processing

Maize grain types vary from very soft, starchy grain with low test weights, through semi-dent and semi-flint, to very hard flinty types (e.g. 'Popcorn') with high test weights. The harder flint types contain more protein and less starch than the soft, starchy types.

The 'grit' varieties, which produce the hard semi-flint kernels, are used to make breakfast cereals, confectionery products or specialty products such as corn chips.

Grains from 'waxy', 'high amylose' or white maize hybrids have special starch properties needed for other areas of industry and food processing.

If the grain is going to be processed the grower must select hybrids that are recommended by the particular manufacturer, as they will not accept other hybrids.

Maize for stockfeed

Varieties used for stockfeed are chosen mainly for their yield potential rather than their grain quality.

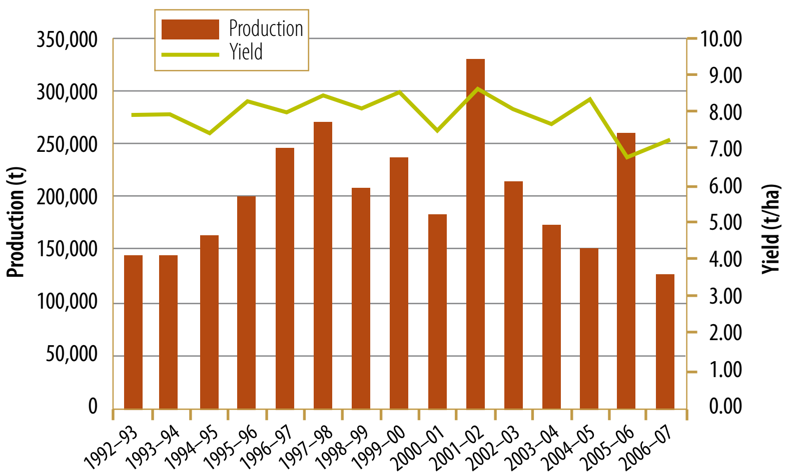


Figure ii. NSW maize production for 1993–2006. Source: Scott (2007)

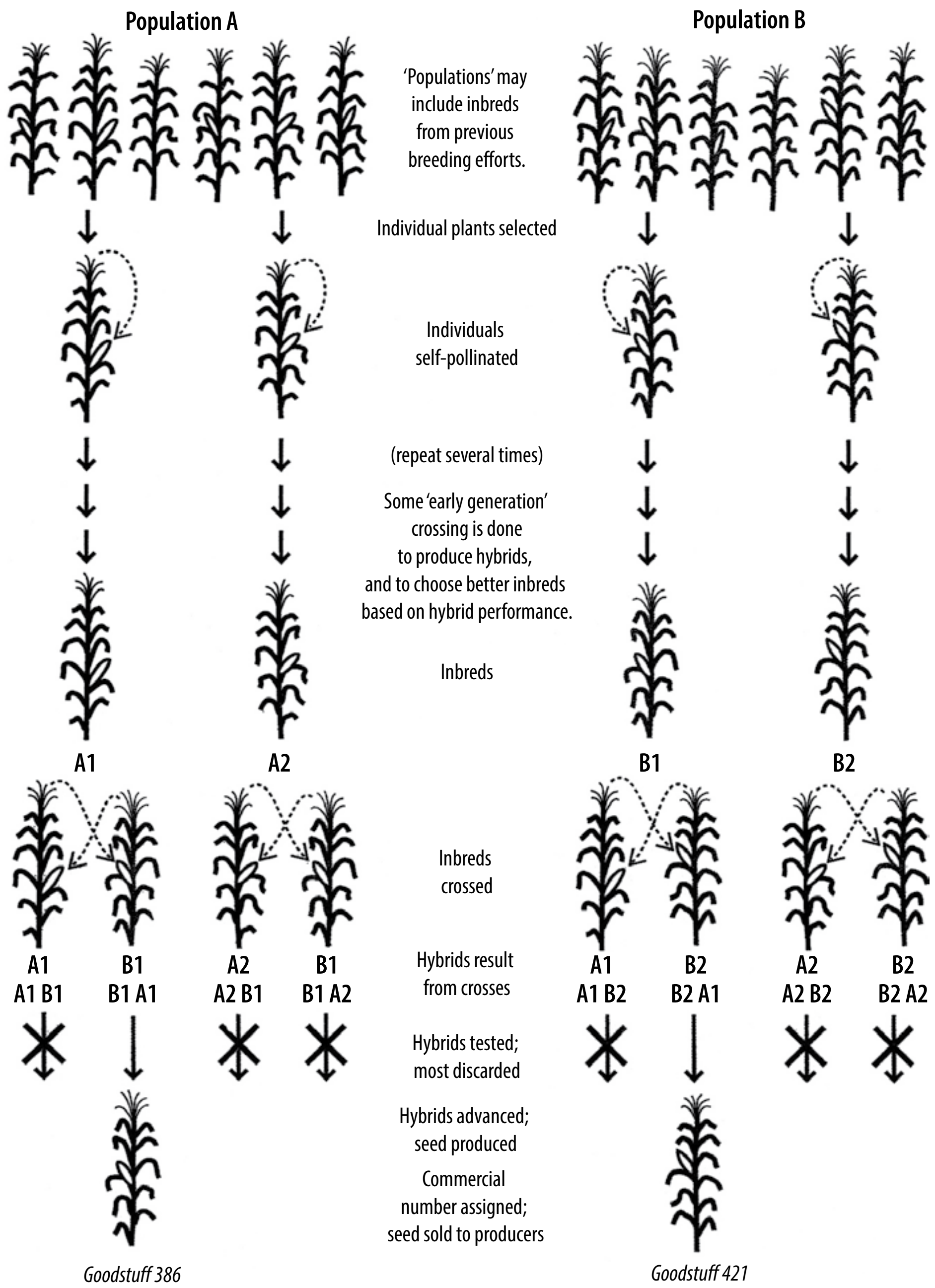


Figure iii. Example of a breeding scheme for maize, showing how hybrids are produced. Source: Hoeft et al. (2000)

Table i. Characteristics of the hybrids available for the 2008–09 season. Source: NSW DPI (2008)

HYBRID	CRM[Δ]		NSW AREA OF ADAPTATION	END USE	HUSK COVER[∞]	DISEASE REACTIONS[◊] MOSAIC VIRUS	DISEASE REACTIONS TURCICUM LEAF BLIGHT	DISEASE REACTIONS RUST	DISEASE REACTIONS COB ROT	DISEASE REACTIONS WALLABY EAR	LODGING[^] ROOT	LODGING STALK	COMPANY RECOMMENDATIONS TARGET PLANT POPULATION/HA × 1000 IRRIGATION	DRYLAND > 650 MM	DRYLAND < 650 MM	SEED BRAND
Emperor TL	90	Quick	Inland; South Coast	Silage	M	–	4	5	–	–	5	6	85–105	45–60	30–40	HSR
38F70	95		Southern Inland	Silage	M	–	7	–	5	–	–	7	80–100	–	–	Pioneer
DK 477	97		Southern Inland	Feed; Silage	M	7	7	7	7	6	8	8	80–100	45–60	NR	Pacific Seeds
Julius	98		South Coast	Feed; Silage	M	–	6	7	7	–	8	8	80–110	45–60	30–40	HSR
36H36	100		Inland; South Coast	Silage	MT	–	5	5	5	–	–	8	80–100	–	–	Pioneer
Titus TL	100		Inland; South Coast	Silage	MT	–	4	5	–	–	6	6	75–100	45–60	**30–40**	HSR
Hycorn 502IT[o]	104		Southern Inland	Feed; Silage	M	5	5	6	6	5	8	7	75–95	45–60	25–35	Pacific Seeds
Maximus	102		All	Feed; Silage	M	–	8	9	7	–	9	9	80–100	45–60	30–40	HSR
36B08	103		Southern–Central Inland	Feed; Silage	MT	–	7	5	6	–	–	7	75–95	–	–	Pioneer
Hercules	105	Medium–quick	Inland; South Coast	Feed; Silage	M	–	5	5	7	–	7	7	70–105	45–60	30–40	HSR
3527	106		Central Inland	Feed; Silage	MT	5	5	5	7	5	–	8	70–90	50–70	30–40	Pioneer
Roman	107		All	Feed; Silage	M	–	7	8	7	–	8	8	70–105	45–60	30–40	HSR
34H98	108			Waxy	MT	–	6	6	7	–	–	8	70–90	–	–	Pioneer
34B28IT*	109		Inland	Feed; Silage	M	–	4	6	7	–	–	7	70–90	–	–	Pioneer
Hycorn 533	109		All	Feed; Silage	M	7	5	7	6	6	8	8	75–95	45–60	25–35	Pacific Seeds
34N43	110		Inland; South Coast	Feed; Silage	M	–	6	5	7	–	–	8	70–90	45–65	–	Pioneer
Colossus	110		All	Feed; Silage	VT	–	5	7	7	–	8	8	70–90	40–60	25–35	HSR
3395IR[#]	111			Feed; Silage	M	4	4	6	5	3	–	8	70–90	45–65	30	Pioneer
Cobber – Flint	112		North Coast; Inland limited irrigation	Grits; Feed	T	8	8	6	8	–	–	8	70–90	35–65	25–35	Lefroy Seeds
Hannibal	112		All	Feed; Silage	MT	–	7	7	9	–	9	9	70–85	35–60	25–35	HSR
Olympiad	112		All	Feed; Silage	M	–	8	8	8	–	9	9	85–95	40–55	25–35	HSR
Thunderpop	112			Butterfly Popcorn	MT	–	7	7	8	–	7	7	60–75	40–50	25–30	HSR
3335	113	Medium	Southern–Central Inland	Feed; Silage	M	5	5	5	5	–	–	8	–	–	–	Pioneer
33T39	113		All	Waxy	M	–	5	4	7	–	–	7	70–90	45–65	–	Pioneer
32H39	114			Feed; Chips (white)	MT	6	4	5	7	–	–	8	70–90	–	–	Pioneer
33V15	114		All	Feed; Silage	M	–	6	4	7	–	–	7	70–90	45–65	–	Pioneer
Blaster	114			Mushroom Popcorn	MT	–	7	7	8	–	7	7	60–75	40–50	25–30	HSR
Victory	114		North Coast; Inland limited irrigation	Grits; Feed; Silage	VT	–	8	8	8	–	–	–	NR	25	32	Lefroy Seeds
33A63	115			Waxy	MT	5	5	5	5	–	–	8	70–90	–	–	Pioneer
Hycorn 424	115		All	Feed; Silage	MT	8	7	7	6	6	7	6	60–70	35–45	20–35	Pacific Seeds
3287W	116			Feed; Chips (white)	M	6	5	6	7	–	–	7	–	–	–	Pioneer
32P55	117		All	Grits; Feed; Silage	MT	–	7	7	7	–	8	8	60–75	30–45	–	Pioneer
3153	118		All	Grits; Chips; Silage	T	7	7	7	8	6	–	9	60–75	30–45	25	Pioneer
3237	118		Northern Inland; North Coast	Feed; Silage	MT	5	5	5	6	5	–	9	60–75	30–45	25	Pioneer
31G66	118		All	Feed; Silage	T	–	5	–	8	–	–	8	60–75	30–45	–	Pioneer
Hycorn 675IT[o]	118		All	Feed; Silage; Chips	MT	6	7	7	7	8	8	7	65–75	35–45	20–35	Pacific Seeds
XL80	118		Inland	Feed; Grits	MT	5	5	6	8	6	8	6	60–70	35–45	NR	Pacific Seeds
Hycorn 345	119		Inland	Feed; Grits; Chips	MT	5	5	7	8	6	8	6	60–70	35–45	25–35	Pacific Seeds
Hycorn727	123	Medium–slow	Northern Inland; North Coast	Feed; Grits; Silage	MT	8	6	7	7	7	8	7	55–70	35–50	20–30	Pacific Seeds
C79	123		North Coast	Feed; Grits; Silage	M	–	9	7	8	7	–	8	60–75	30–45	22	Pioneer
31H50	123		South-Central Inland; South Coast	Silage	T	–	8	8	8	–	–	–	50–65	30–45	–	Pioneer
Hycorn 901	126		North Coast	Feed; Silage	MT	8	8	9	8	5	7	8	55–65	35–45	20–30	Pacific Seeds

[o] IT = imidazoline tolerant; [#] IR = imidazolinone resistant [∞] Husk Cover; M = moderate; MT = moderate/tight; T = Tight; VT = Very Tight [^] Lodging Resistance: 1 = Poor; 5 = Average; 9 = Excellent
[◊] Disease Reactions: 1 = Highly Susceptible; 5 = Intermediate; 9 = Highly Resistant NR = Not Recommended; – = No Information; [Δ] CRM = Corn Relative Maturity

Maize for silage

Maize can also be cut to make silage (Figure iv). Hybrids are grown for the maximum amount of dry matter per hectare. To do this they need to grow over the full season at a high plant population. Hybrids are selected for high grain yield because the higher the grain to stover ratio, the better the silage feed quality. They should also retain a high proportion of green leaf through to harvest.

Selecting varieties

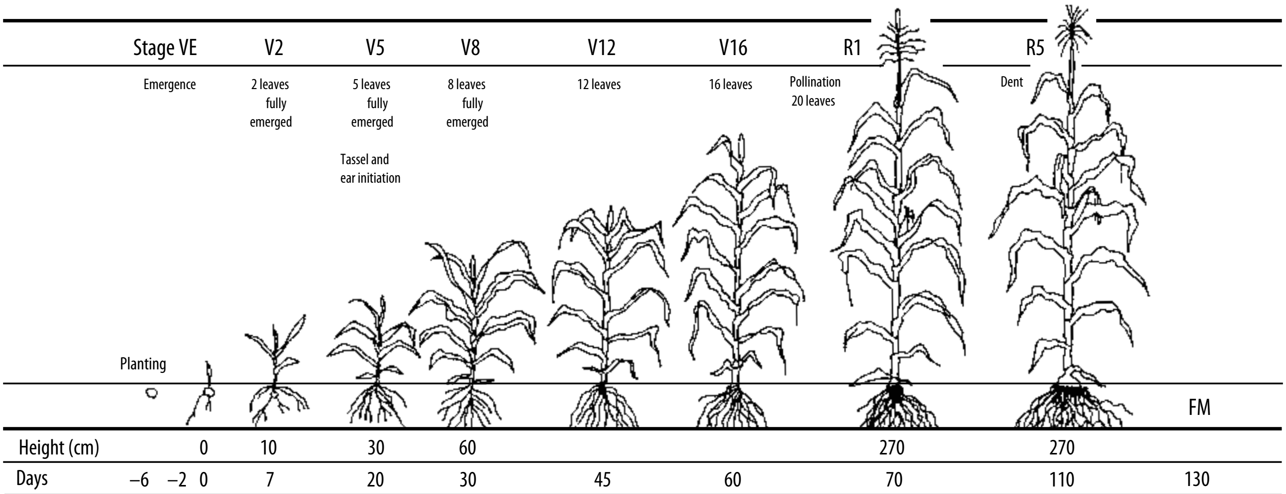
All varieties recommended for NSW are hybrids. For details on the grain varieties available this season, see the current *Summer Crop Production Guide* (NSW DPI 2008) and Table i.

Life cycle

The growth and development of the maize plant are complex processes. During the life cycle of the plant, many of the growth stages overlap, and while one part of the plant may be developing another part may be dying. Figure v represents the progression of the key growth stages and the basic parts of the maize plant.

Growth of a maize plant is defined as the accumulation of dry matter. **Development** is concerned with the plant's progression from being vegetative (i.e. growing) to reproductive. During the life cycle of the plant there are several key identifiable stages at which the plant's requirements must be met to ensure high yields.

Figure iv. Use of maize for silage production has increased in recent years because of the establishment of cattle feedlots. Photo: Steven Smith



% Water	1	2	4	5	7	10	11	12	12	11	8	6	5	3	2	1	1
% N	1	1	1	2	7	11	14	15	16	12	10	6	4	2	1	1	1
% P	1	1	1	1	2	4	7	10	11	15	13	11	9	8	5	2	1
% K	1	1	1	3	9	16	21	20	16	8	5	1	–	–	–	–	–

Figure v. Growth stages, basic parts of the maize plant and water and nutrient requirements. Source: Colless (1992)

Pericarp (seed coat)
The outer protective covering of the kernel.

Endosperm
A nutritive tissue within the seed that surrounds the embryo and provides energy for germination. The germinating seed relies on these reserves until it has developed a root system. The endosperm makes up the bulk of the grain and stores the starch and protein that are milled.

Embryo
Contains the main plant structures, so holds all the elements of the growing plant. It is made up of the scutellum, plumule (shoot) and radicale (primary root). The embryo is found at the end of the kernel that is attached to the cob.

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.

Plumule
The growing point of the kernel that develops into the shoot bearing the first true leaves. At the growing point are the coleoptile, three leaf primordia and the shoot apex.

Radicle
Develops into the primary root and is the first structure to emerge from the kernel after germination.

Defining maize growth stages

Crop managers need to be able to identify the different stages of growth. The most common system used for defining maize growth stages divides the growth cycle into two parts: vegetative growth and reproductive development.

Vegetative growth stages

Vegetative growth stages are determined using the Leaf Collar method. A plant is assigned a growth stage depending on the number of visible leaf collars present. Vegetative stages defined by this method are named 'V' stages. For example, a plant with seven visible leaf collars (see Figure v) would be at 'V7'.

As the maize plant progresses through growth stages V4 and V5, some of the earlier leaves may have fallen off because of stem expansion and aging. To determine the vegetative growth stage, split the stem and locate the fifth leaf node. The fifth leaf node is located above the first visibly elongated node at the base of the stem.

From this point, the V-stage is determined by counting the nodes upwards until the highest leaf node is identified.

The final V-stage is VT. This is when all the branches of the tassel are fully emerged (Figure vi).

Reproductive development stages

Reproductive stages are defined by using an 'R-stage' instead of the V used for vegetative growth stages. Growth stage 'R1' is defined as silking – the emergence of silks beyond the tip of the ear husk (Figure v). The rest of the R stages relate to the development of the kernels on the ear. The husk needs to be removed to enable the identification of these next stages.

Seeds start developing as soon as they have been fertilised. The first ones to be fertilised are at the base of the ear, and the last seeds to be fertilised are at the ear tip. In assessing the reproductive growth stage, only the seeds in the middle section of the ear are assessed.

The maize kernel

The kernel or seed of the maize plant has three main parts: the **pericarp** or **seed coat**, the starchy **endosperm**, and the germ or **embryo** (Figure vii). The pericarp protects the kernel before and after planting against entry by fungi and bacteria. The endosperm provides energy for the young plant until its roots and leaves are well established. The embryo contains the parts that will first develop in a new seedling, including the growing point, the first five to six leaves, and the initial root.

Figure vi. VT stage is when all the branches of the tassel are fully emerged. Source: Kieran O'Keeffe

The maize plant

The main structures of the plant are the coleoptile, leaves, stalk, roots, ear and tassel. Unlike all other major grain crops, the maize plant has separate male and female flowering structures – the tassel and the ear. When both flowering structures are located on the same plant, as they are in maize, the plant is called monoecious.

Coleoptile

The coleoptile is a pointed, modified leaf that surrounds and protects the plumule (four or five leaves rolled up, one inside the other) during germination. Such protection is valuable as the coleoptile elongates, pushing the plumule through the covering of the kernel (pericarp) and then through the soil to the surface.

Leaves

The leaf (Figure viii) consists of the leaf blade, leaf midrib and leaf collar and sheath. Leaves are produced in a set order on alternate sides of the stem.

The leaf blade is the nearly flat part of the leaf where the process of photosynthesis occurs. The leaf midrib extends the length of the middle of the leaf blade from the base to the tip. It provides structural support. The collar is the area on the inner surface of the leaf where the leaf blade and leaf sheath join. The sheath is the leaf portion (below the collar) that wraps around a stalk and attaches the leaf to a stalk node.

The stalk

The stem is made up of nodes and internodes and provides structural support for the leaves to intercept sunlight.

The roots

The root system consists of lateral seminal roots, nodal roots and brace roots. The lateral roots grow directly from the kernel. These roots provide anchorage

Monoecious
A plant with both male and female flowers.

1. Ear leaf
2. Seed coat
3. Endosperm
4. Embryo
4a. coleoptile
4b plumule
4c scutellum
4d radicle
5. Black abscission zone
6. Pedicel

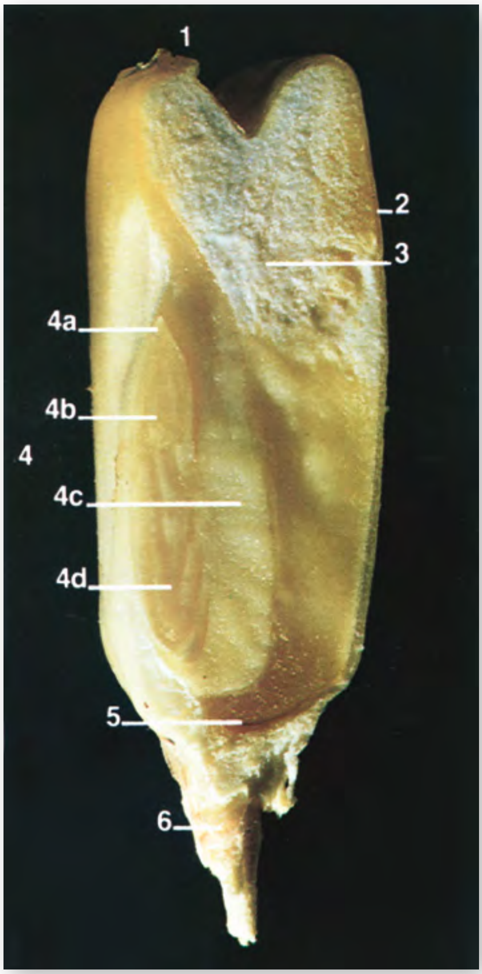


Figure vii. Parts of the maize kernel. Source: Hoeft et al. (2000)

Figure viii. The maize leaf. Photo: Kieran O'Keeffe for seedlings until about V3, when the nodal roots have developed sufficiently. The nodal roots extend directly from each node of the first six to eight stalk nodes below the ground. The brace or crown roots form later in the season at nodes just above the soil surface.

The ear

The 'ear' of the maize plant is a central cob with a cylindrically arranged group of flowers, each consisting of an ovary that has an attached silk (actually a very elongated style) and is capable of producing a kernel if fertilised successfully. On a well developed ear there are 700 to 1000 potential kernels, or ovules, arranged on the cob, with typically about 50 per row long and 12 to 24 rows round (Figure ix).

The tassel

The tassel is the male flowering structure of the maize plant (Figure x). Unlike all other major grain crops, the maize plant has separate male and female flowers. The only function of the male flower (the tassel) is to produce pollen to fertilise the female flower (the ear). The number of pollen grains produced by a tassel is usually between 2 million and 5 million. If there are 1000 silks per ear, then there are 2000 to 5000 pollen grains produced per silk. Maize is a wind-pollinated plant and therefore produces copious quantities of pollen; this increases the chance of a pollen grain landing on each silk and thus the chances of fertilisation occurring.

Figure ix. The maize 'ear'. Photo: Steve Smith

Figure x. The maize tassel. Photo: Kieran O'Keeffe

References and further reading

Colless JM, 1992. *Maize growing*, Agfact P3.3.3, second edition. NSW Department of Agriculture, Orange.

Hoeft R, Nafziger, E, Johnson R, Aldrich S, 2000. *Modern Corn and Soybean Production: How the Corn Plant Develops*. Special report no. 48, Iowa State University, Ames, Iowa.

Huang R, Birch CJ and George DL, 2006. Water use efficiency in maize production – the challenge and improvement strategies. In *Maize Association of Australia Conference Proceedings 2006.*

Kaiser A, Colless J, Lawson J, Nicholls C, 1997. *Australian Maize*, Kondinin Group, Redlands WA.

Maize Australia 2006. *Water to Gold.* Proceedings of 6th Triennial Conference of the Maize Association of Australia, Griffith, NSW, Australia. Maize Association of Australia, Shepparton, Victoria.

NSW DPI 1998–2007. *NSW Grains Report*. NSW Department of Primary Industries, Orange.

NSW DPI 2008. *Summer Crop Production Guide 2008*. NSW Department of Primary Industries, Orange.

Scott, F, 2007. *NSW Grains Report Summary,* NSW Department of Primary Industries, Orange.

Purdue University 1999. Corn Growth, Development and Diagnostics. 2 CDs, Germination to Knee-high and Knee-high to Maturity.

Ritchie S, Hanway J, Benson G, 1992. How a Corn Plant Develops. http://www.extension.iastate.edu/hancock/info/corn.htm

1. Germination and emergence

by Kieran O'Keeffe

Chapter Snapshot

Introduction

Under the right conditions a viable maize kernel germinates. Chapter 1 is about the processes that see the first shoot emerge from the seedbed. The phases covered in this section are germination, emergence and establishment.

Learning Outcomes

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

- describe the germination process
- understand the factors that influence the final plant population
- calculate seeding rate
- calculate establishment density
- calculate Growing Degree Days for different development stages.

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

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

Coleoptile
A protective cylindrical sheath-like structure that surrounds the first leaf.

Mesocotyl
The internode between the coleoptile node and the point where the stem and the root of the young seedling join.

Crown
The point where the plant's roots and vegetative parts join.

Germination – VE

When the maize kernel is planted in moist, warm soil, water is absorbed through the seed coat (this process is called imbibition) and the kernel begins to swell. The kernel accumulates about 30% of its dry weight as water before enzymatic activity in the embryo begins.

Enzymes activate growth in the embryo, and if conditions continue to be favourable the radicle elongates and emerges from the seed coat within 2 or 3 days. The plumule also begins to elongate, and additional leaves begin to form inside this part of the developing seedling. The tiny, soft leaves are enclosed in a specialised leaf structure called the coleoptile, which is pointed on the end and able to grow upward through abrasive soil to bring the leaves to the surface (Figure 1–1).

Figure 1–1. The germinating kernel. Photo: Lowan Turton

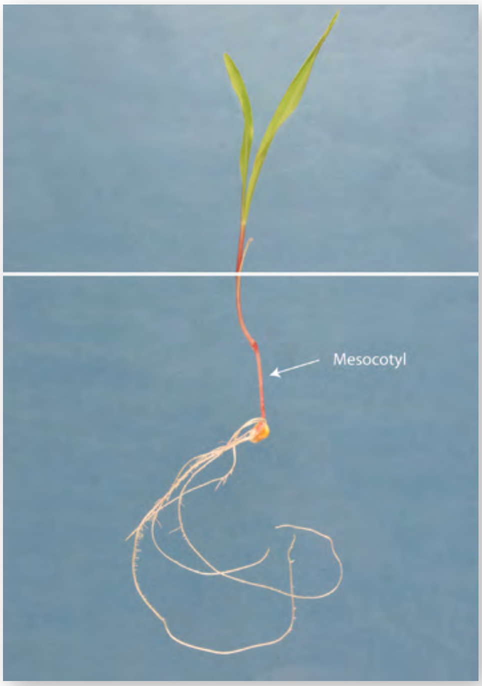


Figure 1–2. The developing seedling. Source: Lowan Turton

The first seedling root (the radicle) is soon followed by several other seminal or seed roots. These anchor the developing seedling and play a role in water and nutrient uptake. The roots that arise from the kernel are called the primary root system.

The primary roots (seminal roots) grow directly from the kernel and maintain the seedling for the first 2 to 3 weeks until the permanent (secondary) root system develops from the crown of the plant. The crown contains the growing point of the seedling and remains about 3 cm below the soil surface until about 3 weeks after emergence.

Between the point of attachment to the kernel and the crown is the mesocotyl (Figure 1–2), a tubular, white, stemlike part sometimes considered the first internode. Both the coleoptile and the mesocotyl elongate as the tip of the coleoptile moves toward the soil surface. Once the coleoptile breaks the soil surface and encounters sunlight, it stops growing and the first leaf breaks through the coleoptile. When light strikes the coleoptile tip, a chemical signal released from the emerged tip helps to fix the depth of the crown, usually about 2 to 3 centimetres below the soil surface. The depth of the kernel is thus not as important as this signal in determining the depth of the crown. The length of the mesocotyl is normally equal to about half the planting depth, but if the kernel is planted deeply then the mesocotyl can be much longer, since the depth of the crown is more or less constant.

Emergence – VE

The coleoptile emerges from the soil 6 to 10 days after planting, but this can be delayed by cool temperatures or dry soil. As soon as the coleoptile tip reaches the sunlight, it splits at the tip and two true leaves unfold (Figure 1–3). In cloddy soil or in the presence of a soil crust or certain herbicides, the coleoptile tip can rupture beneath the soil surface, prematurely releasing the first leaf. Many of these plants die, as the leaves are not strong enough to push through the soil.

By 7 days after emergence, the new seedling has two fully expanded leaves. The primary root system has developed enough to make the plant independent of the dwindling food supply in the kernel. After the first two leaves emerge, the next leaves grow upward inside these leaves (i.e. up through the 'whorl') and unfold at the rate of about one leaf every 3 days, or about one leaf for each 65 growing degree-days that accumulate. (See *Development*, below.)

Figure 1–3. Emergence. Photo: Kieran O'Keeffe

Factors affecting germination and emergence

Germination and seedling establishment are the first critical times in the life of the maize plant. During germination and early growth, the kernel and seedling need oxygen, water, adequate temperatures. They also need an environment free of disease, insects and damaging substances such as salts or certain herbicides. If the soil is too cold, too wet, or too dry, germination may be slow or the young seedling may die before it can become established.

Moisture

Soil moisture influences the speed of germination. Germination and emergence are rapid if the soil is moist.

Water injection may speed germination but may not help the problem of insufficient moisture in the seedbed.

The choice between pre-sowing or post-sowing irrigation depends on soil characteristics, especially surface crusting. Crops grown in the variable soils of southern NSW are commonly sown into a dry seedbed and then irrigated-up. This works best when crops are sown on hills or permanent bed layouts.

Waterlogging

The young plant is very susceptible to damage by waterlogging because the growing point remains beneath the soil surface for the first 3 weeks. If temperatures are high, waterlogging damage can be particularly severe and can retard growth.

Temperature

Germination

Germination depends on temperature. Germination is greatly reduced if the soil temperature is below 10°C. Maize should be sown when the 9 am (Eastern Daylight Saving Time) soil temperature (at sowing depth) is greater than 12°C and increases over the following days. At these relatively low temperatures, seedling emergence will be very slow (14 days or more); at 25°C seedlings emerge in 4 or 5 days.

In irrigated situations, crops that are sown into moisture (from pre-irrigation or stored rainfall) are likely to experience warmer soil temperatures and hence quicker emergence than crops that are irrigated-up.

Development

Temperature is critically important in the development of the maize plant. As temperature increases between a range of 10°C to 30°C, the growth rate increases. Below 10°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. The thermal units used for maize development are called 'growing degree-days', or 'modified' growing degree-days.

Growing degree-days are 'modified' when either the daily minimum or maximum temperature is outside the 10°C to 30°C range. If this occurs the values 10 and 30 are substituted as the minimum and maximum values, respectively. See *In the Paddock* for more details of calculating growing degree-days.

Table 1–1 shows the estimated number of growing degree-days for a mid-maturity hybrid.

Figure 1–4 shows the relationship between growth stage and thermal time (= number of growing degree days) in the maize plant.

Oxygen

Oxygen is essential to the germination process. Kernels absorb oxygen rapidly during germination and without enough oxygen they die. 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 kernels absorb almost no oxygen.

Table 1–1. Estimated number of growing degree-days for the development stages for a mid-maturity hybrid.

STAGE	NUMBER OF GROWING DEGREE-DAYS
Emergence	84
V2	129
V6 (tassel initiation)	282
V10	429
V14	573
VT (tassel emergence)	657
Silking	795
R4 (dough stage)	1087
R5 (dent stage)	1361
R6 (physiological maturity)	1518

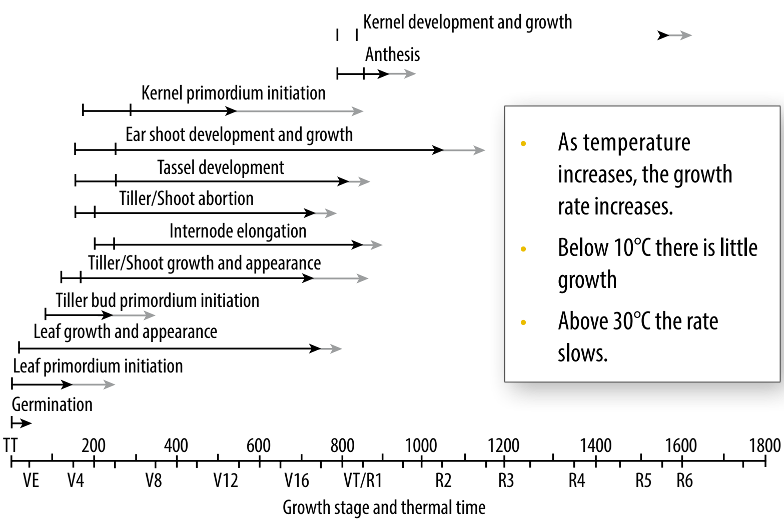


Figure 1–4. Relationship between growth stage and thermal time (growing degree days) in the maize plant. Source: McMaster et al. (2005)

Kernels planted in waterlogged soils cannot germinate because of a lack of oxygen. It is commonly thought that in very wet conditions kernels 'burst', but what actually happens is they run out of oxygen and die.

Nutrition

Because the kernel has stored inside it all the essential nutrients that it needs to begin growing, nutrient shortages are not critical in the first few days. But as the roots begin to take over the job of nourishing the young plant, shortages of elements such as nitrogen and phosphorus can slow growth and development.

Do a soil test before sowing to measure soil nutrients and calculate fertiliser requirements.

Banding fertiliser at sowing ensures that the crop uses the available nutrients from a very early stage of root development. An added advantage of band-applied fertiliser over broadcast fertiliser is that the nutrients remain in an available form for a longer time.

Band fertilisation at sowing time is possible with most modern maize planters. Apply mixed fertilisers (nitrogen, phosphorus and/or potassium) in a band placed 5 cm to the side of the seed and 5 cm below it. This prevents the fertiliser from 'burning' the developing seedling.

Seedbed

Seedbed preparation is also important to emergence. Maize kernels need good soil contact for germination.

Irrigated maize is usually sown on permanent beds with two rows per bed, using precision planters and presswheels (Figure 1–5).

In irrigated fields, old hills or beds with compacted soil or hardpans should be ripped (centre-busted) or chisel-ploughed to ensure good root growth and water infiltration. Where soil compaction problems are suspected, dig a backhoe pit to inspect the profile of the root zone.

Tillage operations performed under wet conditions can cause serious soil compaction and smearing. Stubble retention can reduce soil structural problems or surface crusting. However, if the stubble is kept, adequate nitrogen is needed as there will be some nitrogen tie-up as the stubble residues decompose. Mulching stubble early and getting good soil–stubble contact will allow time for better stubble decomposition and reduce the impact of nitrogen tie-up.

Sowing depth

Seeds should be sown at a depth where there is sufficient soil moisture for seedling emergence. The ideal depth is 4 to 5 cm, although seeds may be sown as deep as 9 cm. Deeper sowing slows seedling emergence. It does not create a deeper root system or enhance the plant's standing ability.

The sowing depth should be uniform to ensure even emergence and a uniform plant stand. The sowing operation is critical for high yields, so care must be taken. Plant stand variability (distance between plants) has a direct negative impact on yield, as shown in Figure 1–6.

Plant population

Each hybrid grown in a particular location will have an optimum range in plant population to maximise yield (see Figure 1–7 and the NSW DPI *2008 Summer Crop Production Guide*).

Between 70% and 90% of the seed sown will produce a plant. Depth of sowing, disease, crusting, moisture and other stresses all reduce plant establishment. Field establishment is unlikely to be more than 90%.

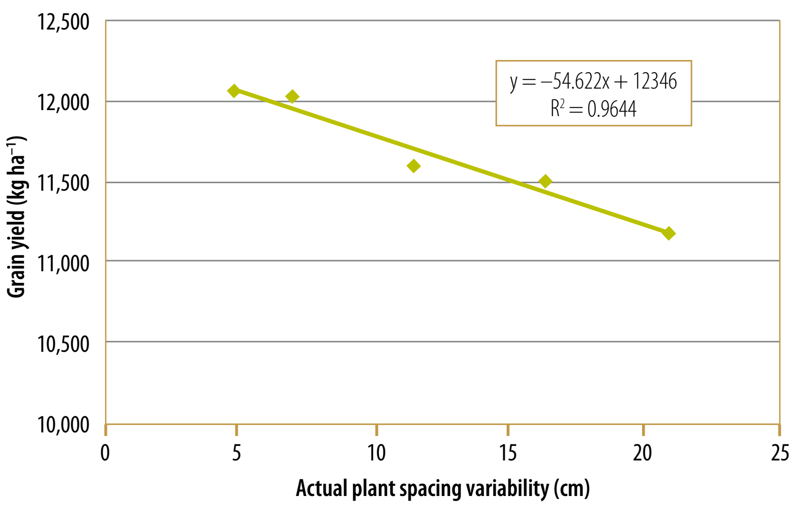
When calculating a sowing rate, allow an extra 5% to 10% for establishment losses under normal growing conditions. See Table 1–2 and *In the paddock*.

The following factors should also be considered when calculating a target plant population.

End use

Green fodder crops are the most densely sown, followed by crops for silage and then grain crops. Non-irrigated crops in drier regions should have lower plant stand densities than crops in irrigated or

Figure 1–5. The sowing operation. Photo: Kieran O'Keeffe



- The data points represent treatment plant spacing variability over nine sets of experiments.
- The results are from large-scale field research in Indiana, USA.
- As the distance between plants increases, grain yield decreases.

Figure 1–6. Relationship between maize grain yield and measured plant spacing. Source: Neilsen (2006)

Table 1–2. Recommended plant populations. Source: NSW DPI (2008)

MOISTURE AVAILABILITY	PLANTS/HA × 1000	
	GRAIN	SILAGE
Irrigated—all regions	60–80	60–100
Dryland		
Coastal	45–55	50–65
Tablelands	40–45	50–60
Northern plains	20–30	–

high rainfall areas. If the only available planting window will expose the crop to high temperatures during ear formation, reducing planting density can reduce moisture stress and mycotoxin risk.

Mycotoxins
Toxins produced by certain moulds growing in the maize. They include aflatoxins and fumonisins.

Soil fertility and available moisture

Fertile soils (including highly fertilised soils) support denser plant stands than do less fertile soils. High fertility can partly compensate for low available moisture levels because well-fertilised plants use available moisture more efficiently, probably because of greater root development.

Type of hybrid sown

Slow-maturing hybrids generally produce larger plants, so they usually grow best if sown at a lower density than faster maturing hybrids. However, the hybrids within any one maturity group have differing tolerances of higher plant density: the more tolerant show resistance to lodging, a low percentage of barren plants and good synchronisation of silking with pollen shedding.

Figure 1–7. Even plant spacing between plants is important to maximise yields. Photo: K O'Keeffe

Planting pattern

Rows are usually sown 75 to 110 cm wide, although the width is ultimately determined by the tractors, harvesters and other equipment available, which must be able to pass through the crop without the wheels damaging the rows. Narrower rows are probably an advantage when there is a high plant stand density and high levels of soil fertility, as plants within the row can then be more widely spaced.

There is evidence to suggest that making the plant spacing uniform within the row is very important for maximising yield (see Figure 1–6).

References and further reading

Colless JM, 1992. *Maize growing*, Agfact P3.3.3, second edition. NSW Department of Agriculture, Orange.

Hoeft R, Nafziger, E, Johnson R, Aldrich S, 2000. *Modern Corn and Soybean Production: How the Corn Plant Develops*. Special report no. 48, Iowa State University, Ames, Iowa.

McMaster GS, Wilhelm WW, Frank AB, 2005. Developmental sequences for simulating crop phenology for water limiting conditions. *Australian Journal of Agricultural Research* 56, 1277–1288.

McCaffery, D. and Boyle, S, 1997. Seedbed preparation crucial for maize. In *Australian Maize*, eds. A. Kaiser, J. Colless, J. Lawson and C. Nicholls. Kondinin Group. pp. 51–60.

Nielsen RL, 2006. Effect of plant spacing variability on maize yield. In *Water to Gold*. Proceedings of 6th Triennial Conference of the Maize Association of Australia, Griffith, NSW, Australia. Maize Association of Australia, Shepparton, Victoria.

NSW DPI 2008. *Summer Crop Production Guide 2008. Part 2: Grains sorghum, maize* (Farrell T, O'Keeffe K). NSW Department of Primary Industries, Orange.

Pioneer Hi-Bred Australia 2007. *Growing Maize for Profit. Maize Workshop.*

IN THE PADDOCK

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

These exercises can be recorded on a MaizeCheck record card (available from Maize Australia at http://www.maizeaustralia.com.au/).

Calculating sowing rate

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

1. Decide on a target plant density (refer to the *Summer Crop Production Guide*).
2. Allow for 10% seedling losses during the early establishment period of the crop.
3. Use the following formula to calculate sowing rates:

$$\text{Sowing rate (kg/ha)} = \frac{\text{desired plant stand}}{\text{seeds/kg} \times \text{germination \%} \times \text{surviving seedlings \%}}$$

Worked example

$$\text{Sowing rate} = \frac{75\,000 \times 10{,}000}{3200 \times 92 \times 90}$$
$$= 28 \text{ kg/ha}$$

Sowing rate: seeds sown (kg/ha)

Desired stand: required number of mature plants/ha

Seeds/kg: indicated on the seed pack.

Germination %: the germination percentage of the seed, expressed as a decimal (e.g. 92% = 0.92). Indicated on the seed pack.

Surviving seedlings %: the percentage of emerging seedlings that produce mature plants, expressed as a decimal (e.g. 90% = 0.9, equivalent to a 10% seedling loss).

Calculating seed spacing along the row

Aim: to calculate the seed spacing along an individual row.

1. The seed spacing within a row for a particular planting rate (kg/ha) may be calculated as follows:

$$\text{Seed spacing} = \frac{\text{desired stand}}{\text{sowing rate (kg/ha)} \times \text{seeds/kg} \times \text{row spacing (cm)}}$$

Worked example

$$\text{Distance between seeds along row} = \frac{10{,}000 \times 10{,}000}{28.3 \times 3200 \times 91.4}$$
$$= 12.1 \text{ cm}$$

IN THE PADDOCK

Calculating establishment density

Aim: to calculate the number of plants established per hectare.

1. Choose 10 representative sites in the paddock.
2. Count the number of plants in 10 m of the bed.
3. Convert the number of plants counted per 10 m of row to the number of plants per ha by multiplying by 1000.
4. If your crop is sown on 1 m rows – 10 m is equal to 1/1000 of 1 ha.
5. For other row spacings use the following table:

ROW WIDTH (CM)	DISTANCE OVER WHICH NO. OF PLANTS IS COUNTED (M)
18	55
35	27
53	19
60	17
75	13
90	11
100	10

6. Is your establishment good/moderate/poor?
7. What percentage of the paddock has weak or patchy establishment?

Calculating growing degree-days (thermal time)

Aim: to calculate the daily growing degree-days for a location.

1. Obtain maximum and minimum daily temperatures for your paddock or farm since planting time.
2. If the minimum temperature is less than 10°C, then use 10°C as the minimum temperature in the equation.
3. If the maximum temperature is above 30°C, then use 30°C as the maximum temperature in the equation.
4. Calculate the average temperature for each day.

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

Worked example

Actual maximum temperature 30°C; Actual minimum temperature 9°C

$$\frac{30 + 10}{2} = 20°C.$$

5. From the average daily temperature, subtract the base temperature, which for maize is 10°C.
6. Add the growing degree-days together to give the accumulated degree-days.

IN THE PADDOCK

7. Using the projected temperatures for the rest of the season, fill in the table below with the dates on which each of the events is expected to occur:

ESTIMATED DEVELOPMENT STAGES FOR A MID-MATURITY HYBRID		
STAGE	NO. OF GROWING DEGREE-DAYS	ESTIMATED DATE
Emergence	84	
V2	129	
V6 (tassel initiation)	282	
V10	429	
V14	573	
VT (tassel emergence)	657	
Silking	795	
R4 (dough stage)	1087	
R5 (dent stage)	1361	
R6 (physiological maturity)	1518	

2. Vegetative growth

by Kieran O'Keeffe

Chapter Snapshot

Introduction

During the vegetative growth phase the maize plant grows quickly and the plant begins storing nutrients for the rest of the life cycle. This is a period of high nutrient uptake, and the plant's progression is influenced by moisture and temperature.

Growth is the increase in the size and number of leaves and stems that produces more biomass. It is time based and is fuelled by photosynthesis, so it relates directly to water use and light interception.

Learning Outcomes

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

- describe the sequence of vegetative stages
- understand the factors that influence vegetative growth, including moisture stress, waterlogging and nutrition
- understand the process of irrigation scheduling to improve water-use efficiency
- estimate and assess plant vegetative stages in the paddock
- estimate the amount of dry matter production at different stages of crop development.

Whorl
Leaves that are not yet unfurled and remain wrapped together in a funnel-like shape. Leaves unfurl from the whorl as the stalk nodes that support them separate through internode elongation.

Tassel
The male flowering structure of the maize plant.

Vegetative growth

V1–V2 stage

These growth stages occur about 1 week after the plant emerges (Figure 2–1). At this stage 1 to 2 leaves are visible on the stem and the primary root system is still relatively small.

The plant is using only small amounts of nutrients but it needs to be in contact with the root system. Banded fertiliser placed underneath the seed will allow effective uptake.

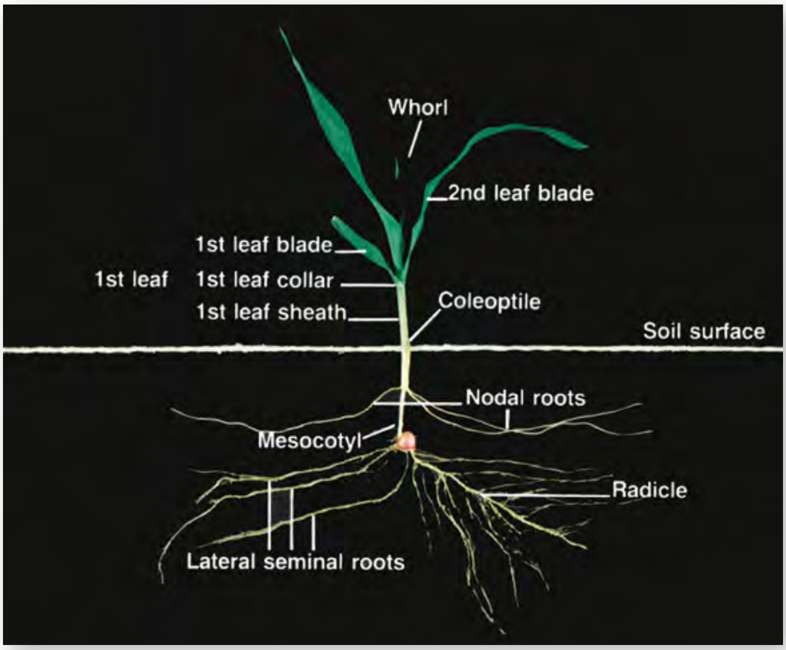


Figure 2–1. A V2 plant. Source: Ritchie et al. (1992)

Figure 2–2. A V3 plant. Source: Ritchie et al. (1992)

V3–V5 stage

Two weeks after the plant emerges, the V3 stage begins (Figure 2–2). The seedling root system has stopped growing and the nodal roots now form the major part of the root system. Root hairs are present on nodal roots. The roots of the second whorl are elongating.

Cultivation too near the plant will destroy some of the permanent root system.

Leaf and ear shoots are being initiated, and this initiation will be complete by V5 (when the potential ear shoot number is determined).

Also by V5, a microscopically small tassel is initiated at the growing point. The plant is about 20 cm high when the tassel is initiated, but the growing point is still at, or just under, the soil surface. However, soil temperature can affect the growing point. Cold soil temperatures at this stage can reduce nutrient availability and slow developmental stages.

Frost or hail may destroy the exposed leaves but will not damage the growing point below the soil surface.

Leaf damage at this time usually results in very little reduction in final yield.

Competition with weeds for water, nutrients and light At this stage, weeds compete for water, nutrients and light. Chemicals, cultivation and higher plant populations or crop rotation used in crop planning can reduce weed pressure and limit the competition to the maize crop.

Ear initiation

The ear, or female flowering structure, is a central cob with a cylindrically arrayed group of female flowers. Each flower consists of an ovary with an attached silk (a very elongated style) and is capable of producing a kernel if fertilised successfully. On a well-developed ear, there are 700 to 1000 potential kernels or ovules arranged on the cob, with about 35 per row and 12 to 24 rows.

The timing of ear initiation varies with maize genetics. A general guideline is to determine which node contains the primary ear (the ear to be harvested) and then subtract seven to give the stage number. This will give a reference point as to when ear initiation started. The V stage when ear initiation started is also when the number of kernel rows around the ear was being established.

For example, the maize line in Figure 2–3 positions the primary ear at the V14 node. This would mean that ear initiation began at or very near the V7 stage.

The location of the primary ear also varies with maize genetics. The maize parent line in Figure 2–3 has a corn relative maturity (CRM; see box on this page) of 103. The primary ear is located on the V14 node. In general, maize lines with a relative maturity between 103 to 118 will produce the primary ear on the V13 or V14 node. Parent lines of earlier maturity will place the primary ear on a lower node, such as the V12 node, whereas maize lines of longer maturity may place the primary ear on a higher node.

Establishing the number of kernel rows around the ear (V5–V8 stage)

Depending on its relative maturity, the maize plant determines the maximum number of rows around the ear between the V5 to V8 stage in its life cycle.

The meristematic dome at the tip of the ear in Figure 2–3 indicates that the developing ear is still producing new rows of ovules along its length. The upper two-thirds of the ear shows a series of single rows of developing ovules. These ovules eventually divide to produce a pair of rows of ovules from each single row. This paired formation is visible near the base of the ear. This division into pairs explains why a maize ear always has an even number of kernel rows around the ear.

The maximum number of ovules that the entire maize ear will produce will be determined after about four more V stages.

Establishment of the number of kernel rows around the ear is a critical event and is susceptible to environmental stress. Knowing when this event occurs helps to establish a 'time window' when looking for a reason. For example, if an ear has 12 kernel rows around instead of the normal 16, then the stress factor that caused this event was present at approximately V7.

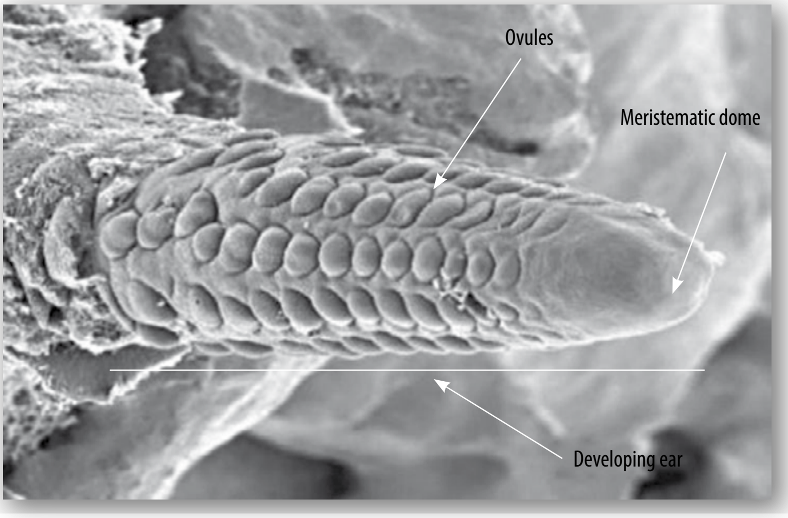


Figure 2–3. Development of the primary ear at node 14. Photo courtesy of Dr Antonio Perdomo, Pioneer Hi-Bred

V6, V7

Approximately 3 weeks after the plant emerges, the plant is at the V6 stage. The root system is well distributed in the soil and extends about 45 cm deep and 60 cm wide. The third root whorl is elongating. The growing point is above the soil surface and rapid stem elongation begins.

The plant is now absorbing greater amounts of nutrients. Row-applied fertiliser is less critical now, as nodal roots have spread throughout the soil. Nitrogen can be side-dressed up to V8 if it is placed in moist soil and excess root pruning and injury of aboveground plant parts are avoided.

Figure 2–4 shows a tassel in a V7 plant. This is a critical stage for yield when the maize ear is setting the maximum number of kernel rows around the ear.

Establishing kernel numbers (V7 – pollination)

From about V7 until pollination the maize plant is determining the length of the ear and the number of kernels along the ear.

Corn relative maturity (CRM)

Determination of maize maturity is based on the times from planting to silking, planting to physiological maturity and planting to harvest maturity.
CRM is an American system that has been used since 1939. It is also known as the 'Minnesota relative maturity system' and the 'comparative relative maturity system'.
The system indicates the rate of maturity relative to a 'standard' hybrid. However, 'relative maturity' should not be confused with 'days to maturity'.
The system incorporates the influence of daylength on the rate of crop maturity. In Australia, CRM is of greatest relevance in southern latitudes (Tasmania, Victoria), equivalent to Minnesota, where the growing season is shorter (fewer warm days) and day length has greatest variation over the growing season.

Meristematic dome

A dome of tissue located at the extreme tip of a shoot or ear.

Figure 2–4. Tassel of a V7 plant. Source: Ritchie et al. (1992)

Ovules near the base of the ear develop first, and newer ovules will continue to form as development progresses towards the tip of the ear. After the maize plant has established the maximum number of ovules, the energy, nutrients and water to sustain these developing ovules must be supplied. If resources are adequate, ovules along the entire ear will develop sufficiently to produce silks and be receptive to pollen. If resources are limited, selected ovules will be sacrificed to allow the maize plant to adequately support the remaining viable ovules. Which ovules are sacrificed depends on the amount, type and duration of the stress.

If the stress is a longer term general stress, ovules near the tip of the ear are sacrificed, resulting in viable ovules only at the base of the developing ear. Ovules near the base of the ear are more likely to remain viable because these ovules are more developed and are closer to the source of nutrient supply. If the environmental stress is very short but very intense, the ovules that are sacrificed may be anywhere along the maize ear.

Very short ears, called 'beer can' ears (Figure 2–5) appear to be due to a combination of environmental stresses – possibly cold stress coupled with drought stress during a critical stage in ovule formation.

Figure 2–5. 'Beer-can' ears. Source: Strachan (2001)

V8, V9

Approximately 4 weeks after the plant emerges, it is at the V8 stage.

The fourth whorl of nodal roots is elongating. Several ear shoots are present. A potential ear shoot will form at every above-ground node except the upper six to eight. Initially, each ear shoot develops faster than the one above, but growth of the lower ear shoots slows. Only the upper one or two ear shoots eventually form harvestable ears.

Prolific hybrids tend to form more than one harvestable ear, especially at lower plant populations.

Nutrient deficiencies at this stage will restrict leaf growth.

Removal of all the unfurled leaves of the plant at this stage (by frost or hail) may result in 10% to 20% reduction in final grain yield.

Waterlogging at this or any earlier stage, when the growing point is below ground, can kill the maize plants in a few days, especially if temperatures are high.

Figure 2–6 shows a V9 plant.

V10, V11

Approximately 5 weeks after the plant emerges the V10 stage begins. The maize plant rapidly accumulates both nutrients and dry matter (Figure 2–7). The time between the appearance of new leaves is shortened, with a new leaf now appearing every 2 or 3 days. Demand for soil nutrients and water is high in order to meet the needs of the increased growth rate. Moisture and nutrient deficiencies at this stage will markedly influence the growth and development of the ears. Fertiliser is needed near the roots – especially phosphorus and potassium, which do not move in most soils.

Two yield components – the potential number of kernels and the ear size – are being determined during the period from V10 to V17.

The length of time for the plant to develop through stages V10 to V17 affects harvestable yield. Early-maturing hybrids normally progress through these stages in less time and have smaller ears than later-maturing hybrids. Therefore, higher plant populations are needed for earlier hybrids to produce grain yields similar to those of mid- to late-maturity hybrids.

V12, V13

Approximately 6 weeks after the plant emerges, the V12 stage begins (Figure 2–8 to 2–10). Brace roots (Figure 2–9) are developing from the fifth node and the first above-ground node. Cultivation of plants at this time will destroy some of the plant roots.

By the V12 stage, the potential number of kernel rows and the potential number of ovules is established. Figure 2–8 shows an ear at the V12 stage from the same maize parent line as that in Figure 2–3 (page 21). The meristematic dome is no longer present, so ovule formation is now complete. Paired ovule formation is apparent along nearly the entire length of the ear.

If an ear has the proper number of kernel rows around the ear but the ear is shorter than normal, then stress of some sort

Figure 2–6. A V9 plant. Source: Ritchie et al. (1992)

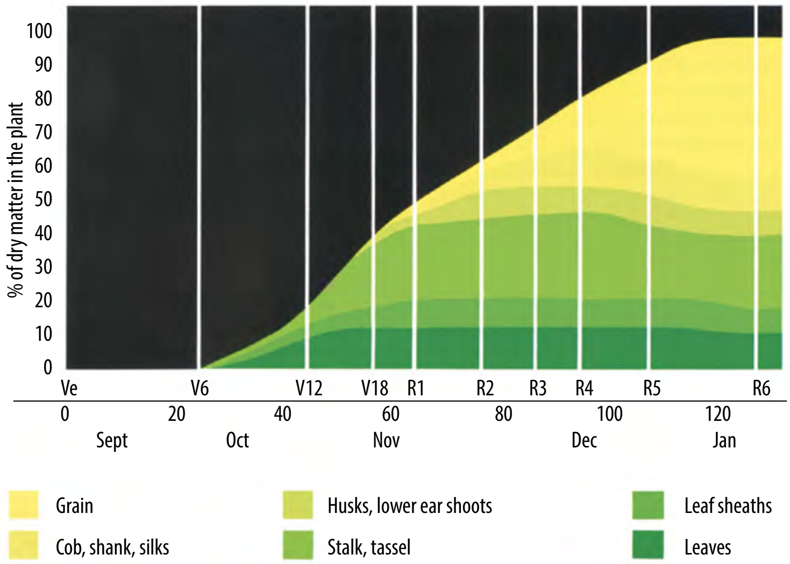


Figure 2–7. Dry matter accumulation at various stages in the maize plant. Modified from Richie et al. (1992)

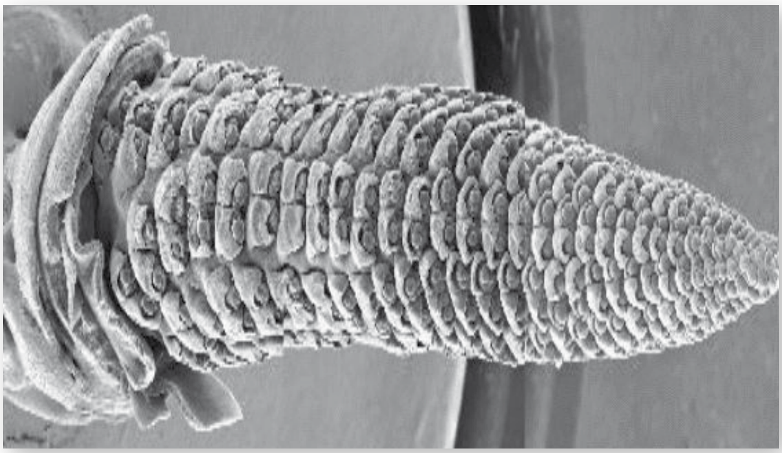


Figure 2–8. Development of the primary ear: V12 stage. Photo courtesy of Dr Antonio Perdomo, Pioneer Hi-Bred

Brace roots
Aerial roots that form at nodes just above the soil surface and extend down to reach the soil surface. They provide support plus extra access to soil moisture and mineral nutrition.

Figure 2–9. Brace roots. Source: Ritchie et al. (1992)

Figure 2–10. Top: Plant at V12. Bottom: The top ear shoot is still smaller than the lower ear shoots, but many of the upper ears are close to the same size. Source: Ritchie et al. (1992)

while the maize plant was around the V12 developmental stage may have caused this event.

V14, V15

About 7 weeks after the plant emerges, V14 begins. The maize plant at V15 (Figure 2–11) is only 12 to 15 days (around five V stages) away from the start of reproductive growth (R1, 'silking'). This vegetative stage is the most critical period of kernel yield determination. The number of ovules that develop silks, and thus the number of kernels, is being determined. Any injury or nutrient or moisture deficiency (such as hail or insects) may seriously reduce the number of kernels that develop. The tassel is near full size but not visible from the top of the leaf sheaths. Silks are just beginning to grow from the upper ears. Upper ear shoot development has surpassed that of lower ear shoots. A new leaf stage can occur every 1 or 2 days. Brace roots from the sixth leaf node are developing and the permanent roots have continued to elongate and proliferate, eventually reaching a depth of about 100 cm and spreading in all directions. In some hybrids, brace roots will also develop from the eighth and ninth leaf nodes or even higher.

V16, V17

Approximately 8 weeks after the plant emerges, it is entering the late vegetative stages if it has not already developed its total number of plant leaves. During this time, plant stress can greatly affect yield. Moisture stress 2 weeks before or after silking can cause a large grain yield reduction. This is also true for other types of environmental stresses (hail, high temperature, nutrient deficiencies). The 4-week period centred around silking is the most effective time for irrigation if water supply is short. The tips of the upper ear shoots may be visible at the top of the leaf sheaths by V17 in hybrids that develop more than 16 leaves. The tip of the tassel may also be visible by V17 in more prolifically leafing hybrids.

V18 or VT

The vegetative plant is reaching full size in prolific-leafing hybrids (Figure 2–12). Silks from the basal ear ovules have been the first to elongate, followed by the silks from the ear tip ovules. Brace roots are now growing from above-ground nodes. These brace roots provide support to the plant and obtain water and nutrients from the upper soil layers during the reproductive plant stages. Ear development is continuing rapidly, with the plant only 1 week away from viable silking. Stress in these later vegetative stages can delay the beginning of pollen shed. If pollen shed is delayed, plants may delay silking until pollen shed is partly or completely finished. If ovules are unfertilised there will be missing kernels on the ear, especially at the ear tip.

Figure 2–11. Plant at V15. Source: Ritchie et al. (1992)

Factors affecting vegetative growth

Moisture

Moisture stress

Even though maize makes efficient use of water, it is considered more susceptible to moisture stress than other crops. This is partly because of its unusual flower structure, with separate male and female floral organs, and partly because all the florets on a single ear develop at the same time. If moisture stress occurs during their development, all will be affected.

The response of maize to water stress varies according to the stage of development. One visible sign of moisture stress is rolling of the leaf margins (Figure 2–13).

During the seedling stage, moisture stress is likely to reduce secondary root development. During the first 4 weeks of growth, moisture stress can result in smaller cobs.

During stem elongation, leaves and stems grow rapidly and need adequate supplies of water to sustain rapid development. Water-stressed plants are shorter with smaller leaves and less leaf area.

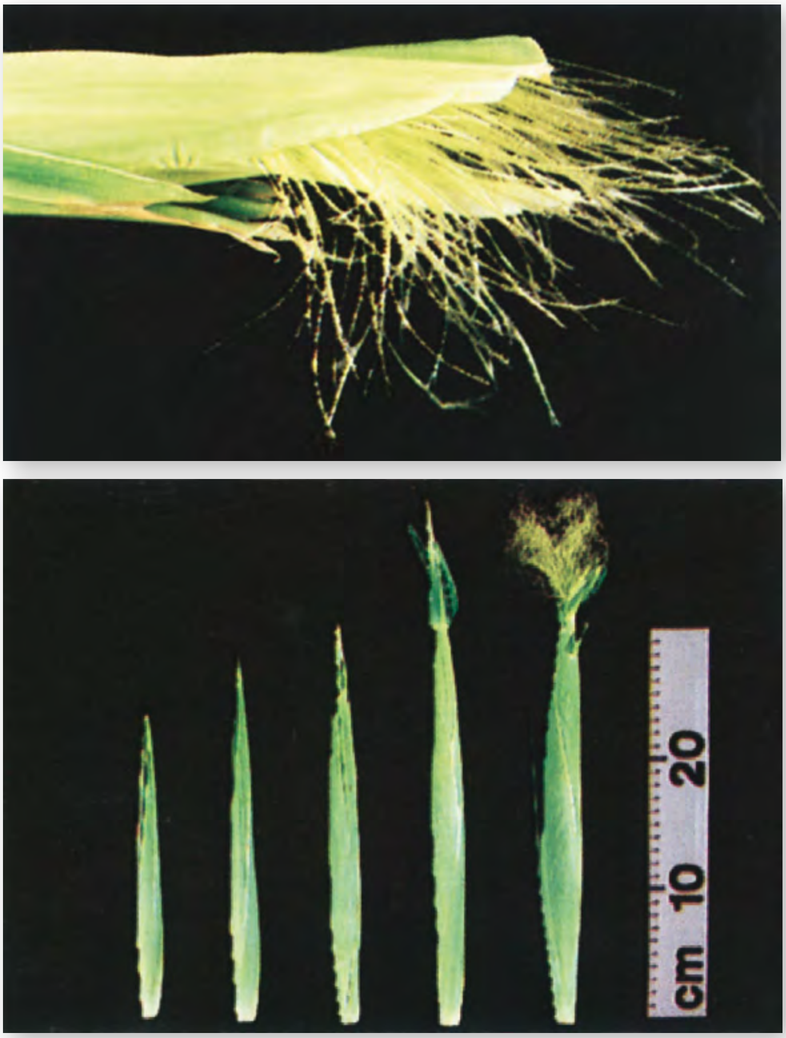


Figure 2–12. Top: Silks emerging in the later V stages. Bottom: Upper ear shoot development. Source: Ritchie et al. (1992)

Moisture stress is particularly damaging to grain yield if the stress occurs after tassel initiation, at flowering, and during mid- to late grain fill.

Figure 2–14 shows that the water need increases rapidly from about 2 weeks before tassel and ear appearance until about 2 weeks after full silking and then decreases rapidly.

Stress at flowering and pollination can result in unfilled kernels on the cob. This can reduce grain yield by 6% to 8% each day the plant is stressed. If the plant is stressed after flowering, kernel size is reduced and the risk of mycotoxin contamination increases.

Waterlogging

Maize is very sensitive to waterlogging. Waterlogging causes low soil oxygen concentration, which limits root function and survival.

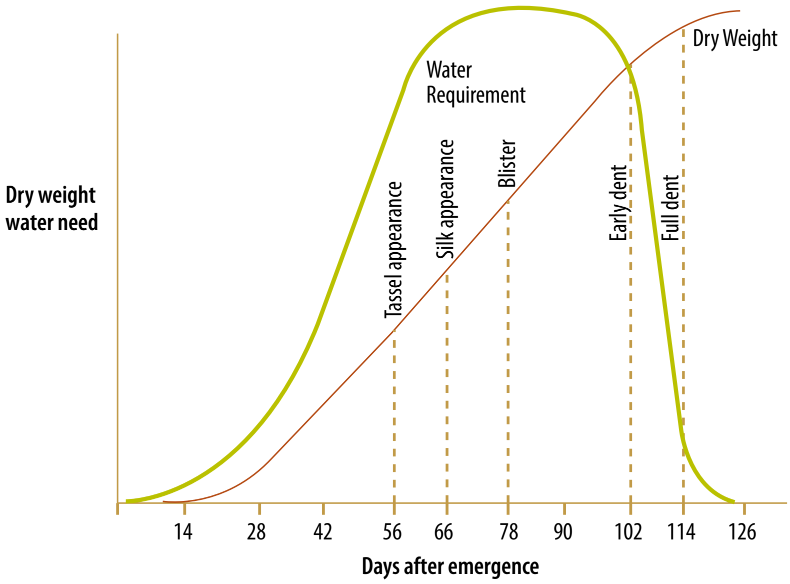
The availability of nitrogen and other nutrients may be reduced by waterlogging, which slows the rate of leaf growth and accelerates leaf death. This reduces yield to a degree but depends on the growth stage at which waterlogging occurs.

Waterlogging that occurs when the growing point is below ground can kill the plants, especially if temperatures are high. Waterlogging at later stages, when the growing point is above the soil surface, is not as detrimental.

Irrigation

Maize is typically irrigated by furrow or flood irrigation, but sprinkler (lateral-move and centre-pivot) irrigation and drip irrigation systems can also be used to grow high-yielding maize crops. Irrigation systems vary in their efficiency, but in all systems some of the water applied to the crop is lost as runoff. Some may also drain through the soil to a depth beyond the roots, and some evaporates from the soil surface. Although there are many factors affecting irrigation system efficiency, furrow irrigation is about 70% to 80%

Figure 2–13. A moisture-stressed crop. Photo: Paul Newell, Pacific Seeds



- Maximum water use occurs from 2 weeks before tassel and ear emergence until 2 weeks after full silking
- Stress at flowering and pollination can result in a 6% to 8% yield loss for every day the plant is stressed.

Figure 2–14. Maize plant water requirements at various times after sowing. Source: Pioneer Maize Workshop notes efficient, spray irrigation about 85% to 90% efficient, and drip irrigation about 90% to 95% efficient.

When maize is grown under irrigation, waterlogging can always be an issue, especially in the early stages of crop development when the growing point is below the soil surface. For this reason many crops are grown on beds or 1 m hills. On free-draining soils maize can still be grown on the flat using border check layouts, but care must be taken in wet seasons not to waterlog the plant.

Frequency

How often you irrigate (usually referred to as 'scheduling') depends on many factors, including:

- soil type
- temperature
- rainfall
- evaporation
- wind
- humidity
- stage of crop growth.

Irrigation scheduling tools

Loggers that continuously monitor moisture at different depths throughout the profile (such as Enviroscans® and C Probes®) have allowed accurate and continuous soil moisture monitoring (Figure 2–15). This technology also allows users to access the information through wireless communication, so soil profiles can be measured from computers some distance away. Other scheduling systems based on weather data (such as the NSW DPI WaterWatch service) are available in major irrigation areas. Figure 2–16 shows the soil moisture profiles of a maize crop on the Liverpool Plains as detected by probe, and Figure 2–17 shows the estimated irrigation requirements for a high-yielding crop at Gunnedah.

Figure 2–15. Soil moisture monitoring is an important tool in minimising crop stress. Photo: Keiran O'Keeffe

- This graph shows the crop suffering serious stress at tasselling (115 mm deficit) and a further stress at the dough stage.

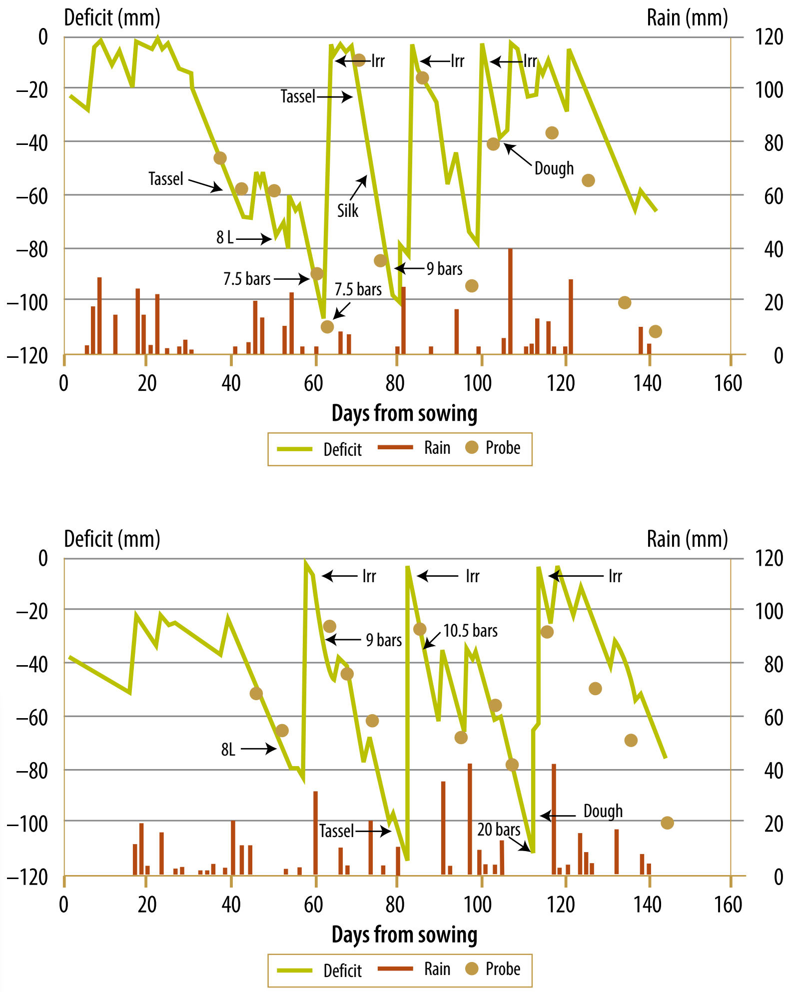


Figure 2–16. Soil moisture profiles for a maize crop on the Liverpool Plains, NSW, in the 1989–90 season. Top graph shows a crop irrigated on schedule (90 mm deficit) just before tasselling. Bottom graph shows a crop that suffered serious stress at tasselling (115 mm deficit) and a further stress at the dough stage. Source: Kaiser et al.

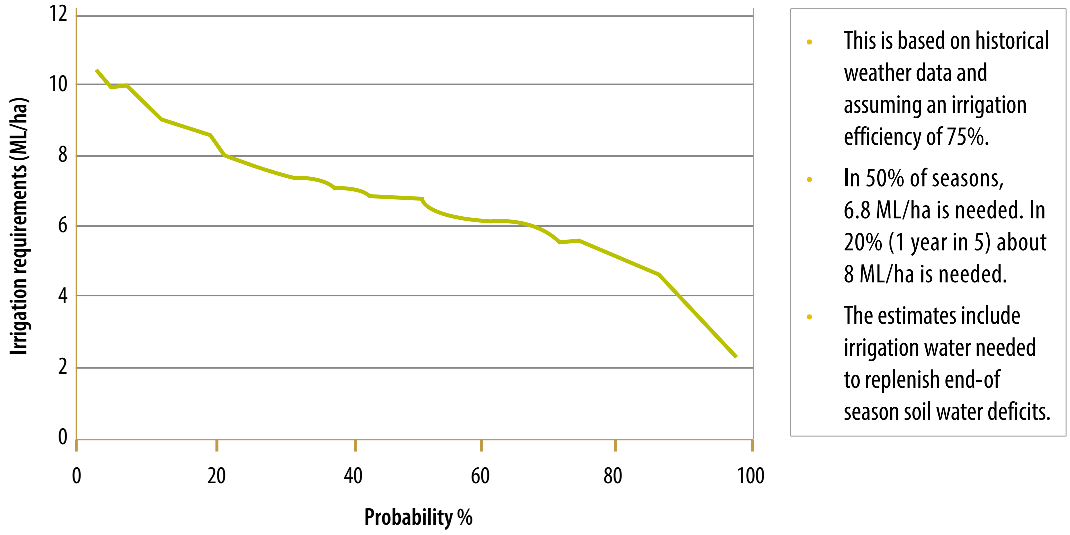


Figure 2–17. Estimated irrigation water requirements for a high-yielding crop at Gunnedah. This is based on historical weather data and assuming an irrigation efficiency of 75%. In 50% of seasons, 6.8 ML/ha is needed. In 20% (1 year in 5) about 8 ML/ha is needed. The estimates include irrigation water needed to replenish end-of season soil water deficits. Source: Kaiser et al. (1997)

Irrigation frequency

Inland crops without rain generally require one irrigation every 10 to 12 days during the flowering and grain-filling stages. Hot dry weather can result in the irrigation interval shortening to 6 to 7 days. Crops in the north of NSW and southern Queensland may need five or six 'in-crop' irrigations, whereas Riverina crops may need 10 or 11 irrigations, depending on the soil's water-holding capacity and the variety.

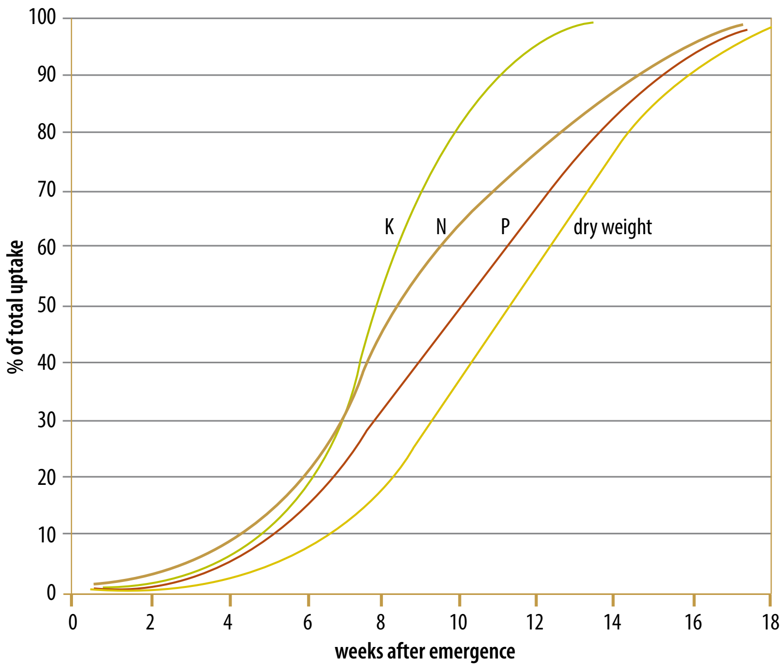


Figure 2–18. Uptake of nitrogen (N), phosphorus (P) and potassium (K), and dry weight accumulation. Source: Colless (1992)

Nutrition

Acceptable yields of grain or silage require high levels of soil fertility. Both require the main essential nutrients (nitrogen, phosphorus and potassium) (Figure 2–18), although a silage crop removes more of these nutrients, especially potassium, from the cropping system. Maize also requires at least 10 other minor or trace elements for normal plant growth and development.

Zinc is one of these trace elements for proper maize growth. Maize grown on heavy clay alkaline soils is where zinc deficiencies can commonly occur. See NSW DPI *Summer Crop Production Guide* for more information.

The young plant takes up small amounts of nutrients, but with growth its nutrient uptake rapidly increases (Figure 2–19).

Nitrogen

The demand for nitrogen increases dramatically about 40 days after seedling emergence. Before this point, the plants have taken up about 18% to 20% of their total nitrogen requirement. However, by the end of silking, they should have 75% of their total requirement.

Figure 2–20 shows the effects of different nitrogen treatments on ear diameter, ear length, and number of kernels per ear. Early-season stress can influence ear development. A deficiency in nitrogen before V8 caused an irreversible decrease in ear diameter and ear length, as well as number of kernels per ear. By looking at treatment N1, we can see that if nitrogen is not applied until after V8 there is a significant yield reduction. Nitrogen was supplied for the rest of the season, but this did not help increase yield, because the ear parameters had been set earlier.

The rate of nutrient uptake (Figure 2–21) in the plant is similar to that of dry matter accumulation (see Figures 2–18 and 2–7). It is important, however, that nutrient uptake begins even before the plant emerges from the soil. The amounts of nutrients taken up early in the growing season are small, but the nutrient concentration in the soil surrounding the roots of the small plant at the early critical stage must be high.

Phosphorus

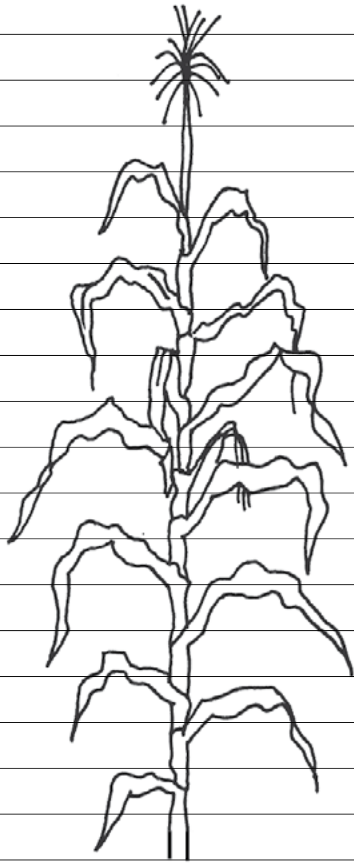
A large proportion of the nitrogen and phosphorus taken up by the plant is removed in the grain at harvest (Figure 2–21).

Potassium

By the end of flowering, the plant has taken up more than 90% of its potassium requirement (Figure 2–21). The plant continues taking up nitrogen until about 2 weeks after flowering, and it keeps taking up phosphorus for a month after flowering.

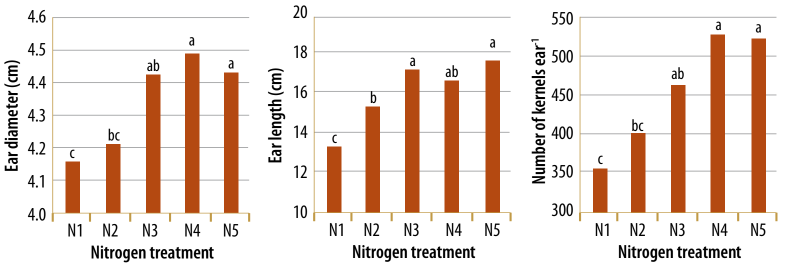
Uptake of potassium is completed soon after silking (Figure 2–21), but uptake of other essential nutrients such as nitrogen and phosphorus continues until near maturity.

Most of the potassium taken up is returned to the soil in the leaves, stalks and other plant residues. Continual removal of plant material through hay-making or silage can lead to potassium deficiency in the soil.



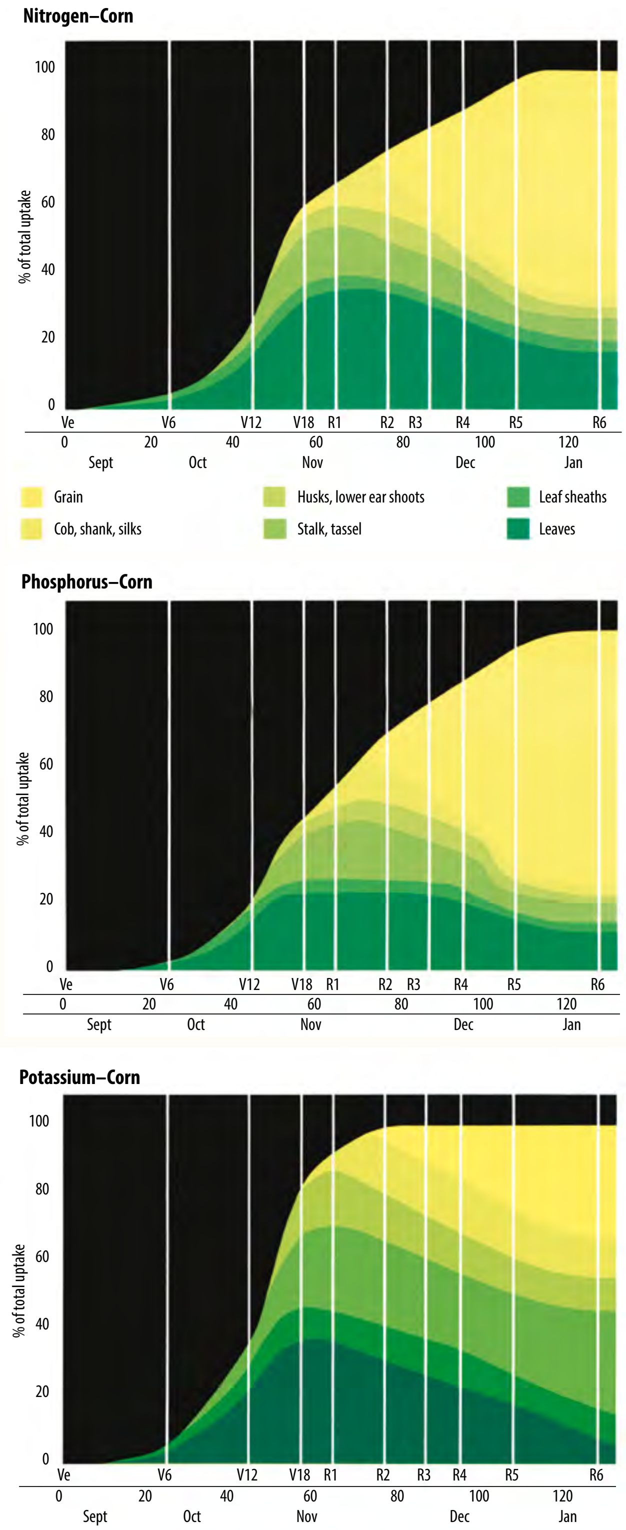
	WEEKLY REQUIREMENTS (as percentage of total need)			
MATURITY	% N	% P	% K	% Water
17 weeks	less than 1	less than 1	–K	less than 1
16 weeks	less than 1	1	–K	1
15 weeks	less than 1	2	–K	2
14 weeks	less than 1	5	–K	3
13 weeks	2	8	–	5
12 weeks	4	9	–	6
11 weeks	6	11	1	8
10 weeks	10	13	5	11
SILKING	12	15	8	12
TASSELING	16	11	16	12
7 weeks	15	10	20	11
6 weeks	14	7	21	10
5 weeks	11	4	16	7
4 weeks	7	2	9	5
3 weeks	2	1	3	4
2 weeks	less than 1	less than 1	1	2
1 week	less than 1	less than 1	less than 1	1
EMERGENCE	less than 1	less than 1	less than 1	less than 1

Figure 2–19. Requirements of major nutrients and water. Source: Colless (1992)



- Ear diameter and weight are set before V8.
- A deficiency in nitrogen before V8 decreased ear diameter and ear length.

Figure 2–20. Effects of different nitrogen treatments on ear diameter, ear length, and number of kernels per ear. See the text for details. Columns with the same letter within each parameter are not significantly different from one another (at P = 0.05). Source: Subedi (2005)



- N demand increases rapidly from 40 days after sowing until about 2 weeks after flowering.
- By the end of flowering, maize has taken up most of its K requirement.
- The uptake of N+P continues until near maturity.

Figure 2–21. Uptake of nitrogen, phosphorus and potassium fertiliser applied at different stages of the life cycle of the maize plant. Day 0 is sowing day. Modified from: Ritchie et al. (1992)

References and further reading

Bolanos J, Edmeades GO, 1996. The importance of the anthesis-silking interval in breeding for drought tolerance in tropical maize. *Field Crops Research* 48, 65–80.

Cakir R, 2004. Effect of water stress at different development stages on vegetative and reproductive growth of corn. *Field Crops Research* 89 (1), pp. 1–16.

Colless JM, 1992. *Maize growing*, Agfact P3.3.3, second edition. NSW Department of Agriculture, Orange.

Grant FR, Jackson BS, Kiniry JR, Arkin GF, 1989. Water deficit timing effects on yield components in maize. *Agronomy Journal* 81, 61–65.

Heisey PW, Edmeades GO, 1999. Maize production in drought-stressed environments: technical options and research resource allocation, Part 1 of *World Maize Facts and Trends 1997–1998*, Mexico DF: CIMMYT.

Huang R, George DL, Birch CJ, 2006. The agricultural water supply challenge—the need for improved water use efficiency. In *Maize Association of Australia Conference Proceedings 2006.*

Jensen ME, 1973. *Consumptive Use of Water and Irrigation Water Requirements.* American Society of Civil Engineers, New York.

Kaiser A, Colless J, Lawson J, Nicholls C, 1997. *Australian Maize,* Kondinin Group, Redlands WA.

Muchow RC, 1989. Comparative productivity of maize, sorghum and pearl millet in a semi-arid tropical environment. II Effects of water deficits. *Field Crops Research*, 20, 207–219.

Ritchie S, Hanway J, Benson G, 1992. *How a Corn Plant Develops*. Special report no. 48, Iowa State University, Ames, Iowa. Retrieved from http://www.extension.iastate.edu/hancock/info/corn.htm on 25.6.08

Shaw RH, 1976. Water use and requirements of maize – a review. *Agrometeorology of the Maize Crop*, World Meteorological Organisation 481, 119–134.

Strachan SD, 2001. Crop insights. Corn grain yield in relation to stress during ear development. GRDC Irrigation update, Tocumwal, 2005, pp 31–38.

Subedi KD, Ma BL, 2005. *Crop Science* 45, 740–747.

White J, 2003. Potassium nutrition in Australian high yielding maize production systems – a review. In *Proceedings of the Fifth Australian Maize Conference,* Toowoomba.

IN THE PADDOCK

The following are some examples of things that can be done in the paddock to illustrate the stages of vegetative growth that have just been discussed. These are practical exercises to help farmers assess the progress of their crops at this 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 out the roots.
3. Find the primary root and determine if 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 growth

Assessing plant growth stage

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

1. Dig up a plant including roots.
2. Count the number of fully unfolded leaves on the main stem.
3. Repeat this procedure with five plants and record the results.
4. Repeat this exercise with different varieties and different sowing dates.
5. Record your results, as below:

PLANT NO.	NO. OF UNFOLDED LEAVES ON MAIN STEM	
	IN PADDOCK 1	IN PADDOCK 2
1		
2		
3		
4		
5		

IN THE PADDOCK

Estimating herbage mass (kg DM/ha)

Aim: to estimate the amount of herbage mass in kilograms of dry matter per hectare.

1. Cut a known area of crop, say 5 metres of two rows of a 100 cm row spacing (10 m^2), i.e. 1/1000 ha.
2. Weigh the wet material from the cut (100%) and convert to dry matter (DM) (65%).
3. A rule of thumb for the potential yield of grain free maize is 650 kg of dry matter or 1 tonne of silage for each 30 cm in crop height per hectare. On-farm cuts of crop will give an indication of potential returns.
4. Estimate forage yields at different crop growth stages by using the following percentages:

MAIZE CROP GROWTH STAGE	% POTENTIAL DRY MATTER AVAILABLE FOR FORAGE
6 weeks (V12)	20%
8 weeks (V18)	40%
9 weeks (R1; silking)	50%
11 weeks (R2; blister)	70%
12 weeks (R3; milk)	80%

Monitoring for pests, diseases, nutrient deficiencies 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.

3. Reproductive development

by Kieran O'Keeffe

Chapter Snapshot

Introduction

During the reproductive stage, the maize plant redirects resources from vegetative growth to pollination and the formation of kernels.

By the time pollination begins, vegetative growth of the plant is complete. The leaves and stalks have reached their full size and the metabolic activities of the plant tissues are at a peak.

Three interlinked stages occur during this phase of development: formation of pollen, fertilisation of the ovule and formation of the kernel.

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

Learning Outcomes

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

- describe the process of flowering (pollen shed and silking)
- understand the important risk factors during this critical stage and how to manage these risks
- assess weather conditions and crop stress at flowering
- assess the success of fertilisation soon after pollination

Reproductive development

Tasselling – VT

The tassel (see Figure 3–1) is the male flowering structure of the maize plant. Figure 3–2 shows a plant going from VT to the R1 stage.

The only function of the tassel is to produce enough pollen to fertilise the ovules in the female flower (the ear). A vigorous maize tassel can produce between 2 million and 5 million pollen grains. If there are 1000 silks per cob, then there are 2000 to 5000 pollen grains produced for each silk. A large volume of pollen is needed because the male and female flowers are physically separated and there are a large number of florets on each plant. A large volume of pollen ensures there is always enough pollen for every exposed silk.

Normally, the tip of the tassel can be seen at about the same time that the tip of the emerging ear becomes visible. The tassel emerges from the enclosing leaves before pollen shed begins (Figure 3–1), which is usually 1 or 2 days before silks first appear.

Flowering (pollen shed and silking) – R1

There are two parts to the pollination process:

- viable pollen must be shed and land on receptive silks

Figure 3–1. This plant is at the VT stage with the tassel fully developed. Source: Ritchie et al. (1992)

- the pollen must germinate and form pollen tubes to allow male gametes (sex cells) to fuse with female gametes inside the ovule.

Figure 3–2. Tassel growth and development from VT through to pollen shed. Source: Ritchie et al. (1992)

Pollen shed

Pollen grains develop and mature in anthers of the tassel, each of which contains a large number of pollen grains. The anthers emerge from the enclosing glumes, usually early to mid-morning after the dew has dried from the tassel. The anthers split open and shed pollen into the air. A minimum of 100 pollen grains/cm^2/day are needed to successfully pollinate a maize field.

Pollen grains are light and can be carried on the wind, but most settle within 5 to 15 m of where they were released. One full-shedding tassel can provide enough pollen for several ears, if the timing and distribution of pollen are right.

Pollen is shed for several days (typically 5 to 10), with peak production on about the third day. Pollen shed begins from the middle of the central spike of the tassel, spreads out over the whole tassel in succeeding days, and ends with shed from the tips and bases of the lower branches.

Pollen shed is not a continuous process. It stops when the tassel is too wet or too dry and begins again when temperature and moisture conditions are favourable, or when additional pollen has matured. On a typical clear mid-summer day, peak shedding occurs between 9:00 and 11:00 am (Australian Eastern Summer Time).

Despite the overlap in timing of pollen shed and silking, pollen of a given plant rarely lands on silks of the same plant. This is due to air movement, leaf placement, and the vertical separation between the tassel and the ear. Under normal field conditions, as many as 97% of the kernels produced by a plant develop from pollen shed by other plants in the field.

Silking

Ordinarily, the first silks produced on a plant emerge from the enclosing husks 1 to 3 days after pollen shed has begun. Under favourable growing conditions, all silks will emerge and be ready for pollination within 3 to 5 days – enough time for all silks to receive pollen before the tassel stops shedding pollen.

As is the case with other plant parts, silk growth takes place mostly at night; studies have shown that silks can grow 5 to 8 cm in a single night. The silks from near the base of the ear emerge first, after growing for several days, and those from the tip appear last. Silks generally appear outside the husks at the end of the ear in the morning, ready to receive pollen as it is shed.

When viable pollen grains fall on maize silks, they are trapped by small hair-like projections called trichomes (Figures 3–3 and 3–4).

Fertilisation and growth of the pollen tubes

Pollen grains contain starch as an energy supply, and they germinate within a few minutes after landing on the trichomes. They produce a pollen tube that grows down the silk channel and enters the ovary (Figure 3–5). These pollen tubes seem to always grow near the silk. This is because the silks supply all of the necessary nutrients and water for growth of the pollen tubes.

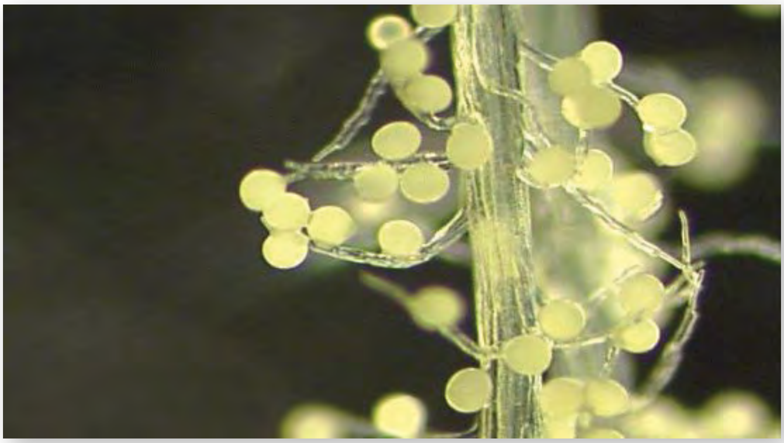


Figure 3–3. Pollen sticking to the trichomes on the silks. Source: Strachan (2001)

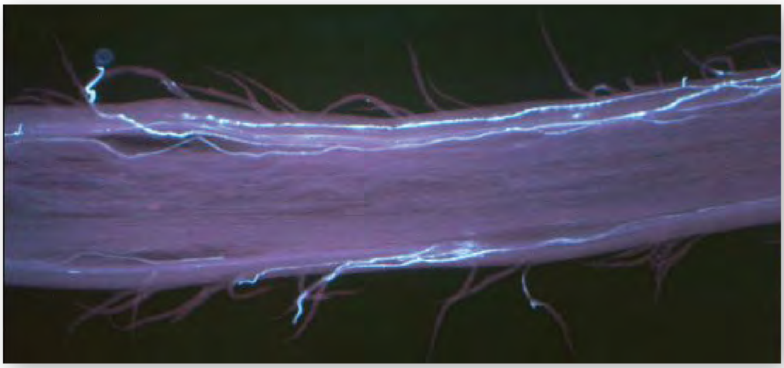


Figure 3–4. Trichomes extending from the main stem of the silk. Source : Strachan (2001)

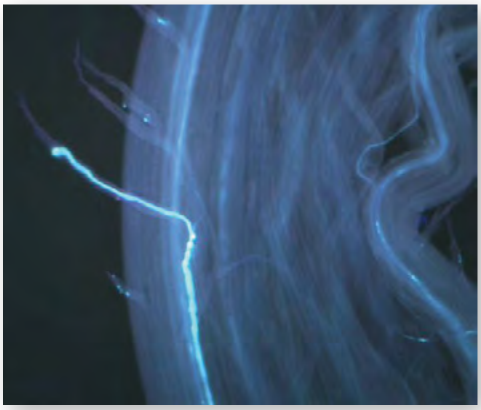


Figure 3–5. Pollen tubes growing along silk vascular tissue.
Photo: Dr Antonio Perdomo, Pioneer Hi-Bred.

Trichomes
Hair-like projections that extend from the main stem of the silk, much like root hairs extend from a plant root

Polar nucleus
One of two nuclei located centrally in a flowering plant embryo sac that eventually fuse to form the endosperm nucleus.

The pollen tube grows the length of the silk in 12 to 28 hours. The pollen tube ruptures at the tip to release nuclei into the ovule, fertilising both the egg, which develops into the embryo, and the polar nuclei, which develop into the endosperm of the new kernel.

After fertilisation, an abscission layer forms near the kernel and the silk detaches, leaving a tiny 'silk scar' on the kernel. Silks that are not pollinated continue to grow, sometimes reaching a length of 15 cm or more.

Depending on water availability and environmental conditions, it may take just a few hours to approximately one day for pollen tubes to grow all of the way to the ovules. When the maize plant is under greater moisture stress, pollen tube growth is slower and the potential for successful fertilisation decreases.

Factors affecting reproductive development

Stress during pollination can have substantial effects on grain yield. A kernel that does not begin developing at this stage cannot start later, and an ear shoot that is not well-formed and fully pollinated can never become a full-sized ear at maturity. Pollination, in other words, functions as an 'on-off switch' for eventual grain yield.

Although the pollination process may seem vulnerable to weather problems, there are some features that help make it work. Pollen does not shed when the humidity is high, so it is not generally washed off the tassel during rain. Also, because silk surfaces tend to be a bit sticky, pollen is usually not washed or blown off after it lands on a silk. Moreover, pollen shedding usually takes place in the morning, before the high temperatures and drying winds of the afternoon.

Moisture stress

The most critical period for moisture stress in maize is 10 to 14 days before and after flowering.

The amount of water available for silk growth substantially influences when silks emerge, their rate of growth, the duration of their receptivity, and their ability to supply water and nutrients to support pollen tube growth and fusion of the gametes (sex cells).

Maize plants that are growing under stress during pollination produce ears with portions of the cobs that are barren

- The amount of kernels that develop depends on the amount of time the silks are exposed to pollen.
- At day 4, the field is at 50% silk.
- The ear in the photo above was exposed for 10 days.

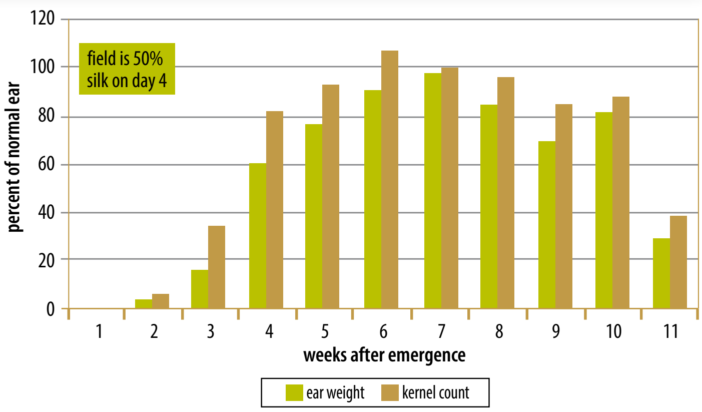


Figure 3–6. The amount of kernels that develop depends on the amount time silks are exposed to pollen. Source: Strachan (2001)

(Figure 3–6). In Figure 3–6 the developing ears were exposed to pollen for one day then covered to exclude pollen again. The ear on the left was exposed for the 10 days of pollen shed. Portions of the cob are barren because mature ovules were not properly fertilised. These unfertilised ovules begin to disintegrate and disappear before the ear reaches physiological maturity.

Moisture stress at flowering or during grain fill reduces the number of kernels per plant and, in turn, grain yield. Grain yield is reduced two or three fold more when moisture stress coincides with flowering than at other growth stages (Figure 3–7).

Moisture stress at full silking will reduce yields by 6% to 8% a day. If moisture stress is combined with nutrient stress, yields can be reduced by 13% a day.

Temperature

Maize is a fast growing crop that yields best with moderate temperatures and a plentiful supply of water.

The ideal daytime temperature is from 26°C to 30°C, but maize can tolerate higher temperatures with full irrigation.

When temperatures reach 38°C or higher, it is difficult to maintain adequate water movement through the plant, even under irrigation.

Night-time temperatures above 21°C can result in wasteful respiration and a lower amount of dry matter accumulation in the plant (Figure 3–8).

The data in Table 3–1 show that high night-time temperatures can reduce yield by 40%.

Pollination

Hot, dry weather conditions are much more likely to interfere with pollination than wet weather.

Pollen may lose viability within a few minutes if air temperatures are high (above 40°C) and water stress is present. Pollen grains contain about 80% water when first shed. These pollen grains die when the water content decreases to about 40%.

Table 3–1. Effect of night-time temperatures during 52 nights following pollination on corn yield at Urbana, Illinois.

TREATMENT	AVERAGE NIGHT-TIME TEMPERATURE °C	GRAIN YIELD T/HA
Natural air	18.3	10.5
Cooled	16.6	10.17
Heated	29.4	6.28

Modified from Hoeft et al. (2000)

- Moisture stress at full silking reduces yield by 6% to 8% per day.
- If moisture stress is combined with nutrient stress, yields can be reduced by 13% per day.

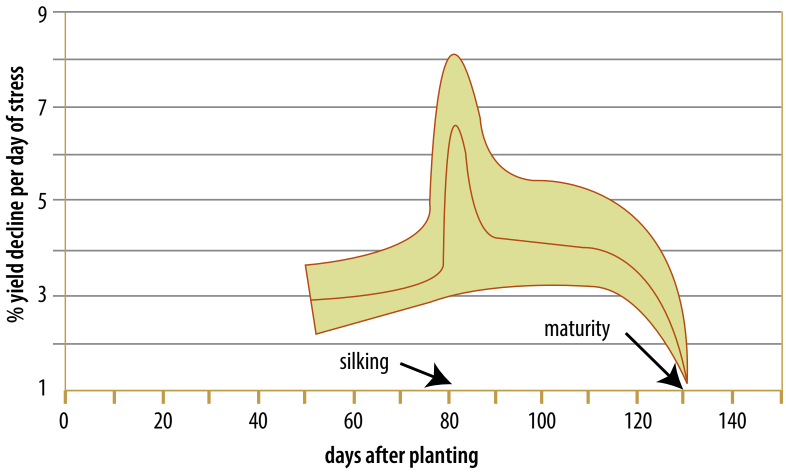


Figure 3–7. Relationship between age of crop and percentage yield decrease due to 1 day of moisture stress. Source: Shaw (1976).

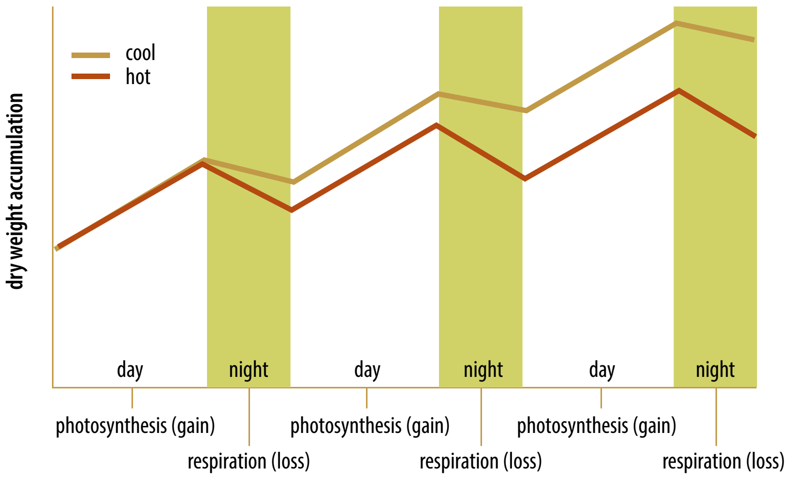


Figure 3–8. Growth here involved accumulation of dry weight from photosynthesis during the day and loss from respiration at night. When nights are too warm, respiration loss is excessive (lower line). The result is similar on a very cloudy, warm day. Source: Hoeft et al. (2000)

Despite this, a lot of maize is successfully pollinated under high-temperature conditions. If soil moisture is adequate and the maize plant can transpire water rapidly enough to supply necessary water to the pollen, the pollen remains viable long enough to properly shed and complete the fertilisation process. However, if the water supply is inadequate, pollen will die prematurely and not complete the fertilisation process.

Silk growth

The most common problem of high temperature is the slow growth of silks, which can result in failure of silks to emerge in time to receive pollen. Poor photosynthetic activity may contribute to this problem. Silks can also dry rapidly under hot, dry conditions and may not contain enough moisture to support pollen germination and growth of the pollen tube to the ovary.

Assimilate supply

The first few days after fertilisation are a very critical period as well. If proteins and sugars are in short supply, kernels near the end of the ear often abort, meaning that they fail to develop even after successful fertilisation. Lack of sugars and proteins may result from lack of water, nutrient deficiencies, reduced photosynthesis due to very cloudy weather, shading from very high plant populations, or damage to leaves from insects or disease. Trial work in the United States has found that 90% shade for 3 days decreased the yield of one hybrid by 25%, and 6 days of shade reduced the yield of the same hybrid by 71%.

Competition from other plant parts

During flowering, ear growth is susceptible to competition from other plant parts. The ear is competing for the limited supply of assimilates from photosynthesis. The result can be low grain number per ear and occasionally barren ears.

References and further reading

Colless JM, 1992. *Maize growing*, Agfact P3.3.3, second edition. NSW Department of Agriculture, Orange.

Dale AB 1986. *How the Maize Plant Grows.* NSW Agriculture.

Hoeft R, Nafziger, E, Johnson R, Aldrich S, 2000. *Modern Corn and Soybean Production: How the Corn Plant Develops.* Special report no. 48, Iowa State University, Ames, Iowa.

Ritchie S, Hanway J, Benson G, 1992. *How a Corn Plant Develops.* Special report no. 48, Iowa State University, Ames, Iowa. Retrieved from http://www.extension.iastate.edu/hancock/info/corn.htm on 25.6.08.

Shaw RH, 1976. Water use and requirements of maize – a review. Agro Meteorology of the Maize Crop, World Meteorological Organisation 481, 119–134.

Strachan SD, 2001. Crop insights. Corn grain yield in relation to stress during ear development. GRDC Irrigation update, Tocumwal, 2001, pp 31–38.

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 crop at this stage.

Assessment of the tasselling/silking or flowering stage

Aim: to assess what if any stress has occurred during the tasselling, silking or flowering stages of crop development.

1. Record the date of tassel emergence
2. Record the date of silk emergence
3. Using the table below, record the stress your crop has been subjected to:

TASSEL EMERGENCE DATE:			SILK EMERGENCE DATE:			
CROP STRESS AT FLOWERING	OCT	NOV	DEC	JAN	FEB	MAR
Number of days with some wilting						
Number of days when greater than 10% of paddock is waterlogged						
Number of days with temperatures above 38°C						

Pollination assessment: ear-shake/silk retention method

Aim: to determine the success of fertilisation

1. Within a week of pollination the silk will collapse at its connection with the fertilised ovule and detach from the immature kernel.
2. Gently unwrap the husk from an ear and gently shake the ear. The detached silks will fall to the ground.
3. Assess the success of fertilisation by looking at the number of detached silks.

4. Kernel development

by Kieran O'Keeffe

Chapter Snapshot

Introduction

Kernel development (grain fill) is the period from flowering to physiological maturity and is the final stage in the life cycle of the maize plant. Carbohydrates and protein are deposited in the kernel as it grows and ripens.

Final yield is determined during this phase and is influenced not only by current conditions and management decisions, but by everything that has preceded it. Grain quality is greatly affected by the conditions during kernel development.

This chapter explains how the kernel develops and reaches physiological maturity and describes the environmental conditions that influence the progression of this stage. Suggestions are provided for management strategies to maximise kernel yield and quality.

Learning Outcomes

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

- explain and understand the kernel filling process and identify development stages
- describe the impact of moisture stress on kernel yield and quality
- determine the timing of the last irrigation
- determine the milk line score of developing crops
- estimate kernel yield
- estimate the water-use efficiency of the crop.

Kernel development

R2 (blister stage)

After fertilisation, the ear continues to grow. For the first few days, little visible change takes place in the fertilised ear shoot, except that the silks wilt and turn brown.

Ten days after fertilisation, developing kernels (Figure 4–1) appear as watery blisters on the cob – called the blister stage or R2 (Figure 4–2). By this time, the cob has reached its full length and diameter.

Dextrin
A short-chain starch molecule

Within the next 2 weeks the kernels grow very rapidly and the developing embryo takes shape within them. At this stage most of the plant's physiological activity is directed toward filling the kernels. Kernel dry weight increases linearly until near the end of grainfill.

Figure 4–1. Kernel attachment to the cob. Source: Strachan (2001)

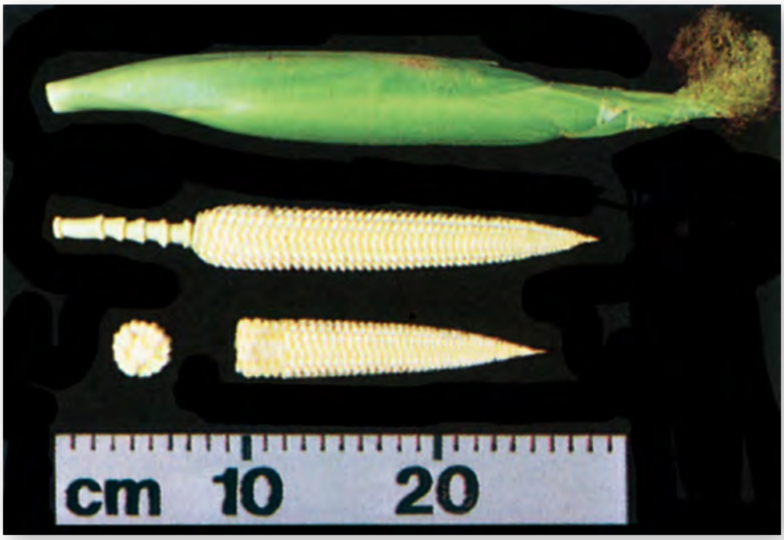


Figure 4–2. The R2 (blister) stage. Source: Ritchie et al. (1992)

R3 (milk stage)

Around 20 days after pollination, the kernels are now yellow on the outside and are filled with a milky, almost fluid substance, high in sugars but containing the beginnings of starch and protein-forming bodies. This is the 'roasting ear', or milk stage (R3) (Figure 4–3). If severe stress occurs during these early reproductive stages the kernels may be aborted from the tip down, to lessen the load on the plant.

R4 (dough stage)

From the time of the beginning of the dough stage (3 weeks after silking) (Figure 4–4) until about 5 weeks after silking, the contents of the kernel undergo a marked change. Sugars continue to pour into the kernel as before, but they are rapidly converted to starch, first in the form of sticky, gummy dextrins, and shortly afterwards into drier starch. Starch is composed of sugar molecules joined together in long chains with the help of starch-forming enzymes.

R5 (dent stage)

The top or crown of the kernel is the first area where hardened, dry starch is deposited. By 40 days after fertilisation at stage R5, or dent (Figure 4–5), a definite band can be seen across the kernel. The band, also referred to as the milk line (Figure 4–6), is the line between the milky deposits and the maturing dry starch.

The amount of dry matter in the kernel is increasing. In the soft dough stage, about 55% of the kernels are starting to dent, and in the hard dough stage more than 90% are dented. By the end of the seventh week of kernel development, the embryo has nearly reached its full size, filling has begun to slow, and the kernel is approaching maturity.

Figure 4–3. The R3 (milk) stage. Source: Ritchie et al. (1992)

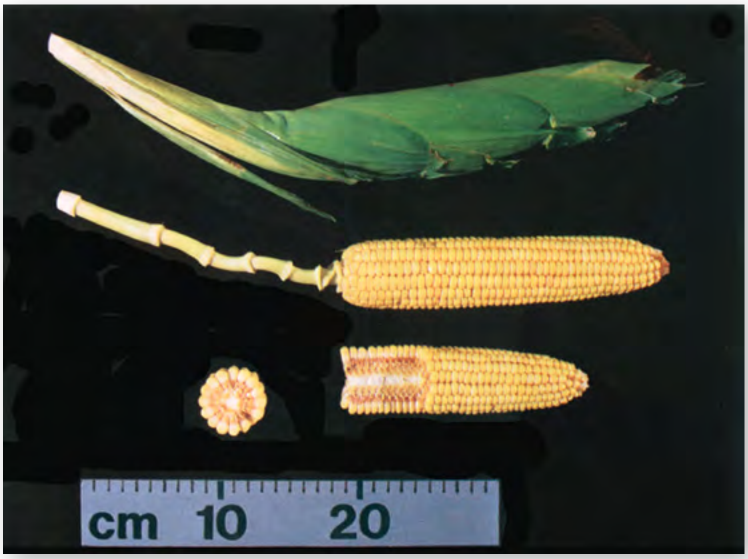


Figure 4–4. The R4 (dough) stage. Source: Ritchie et al. (1992)

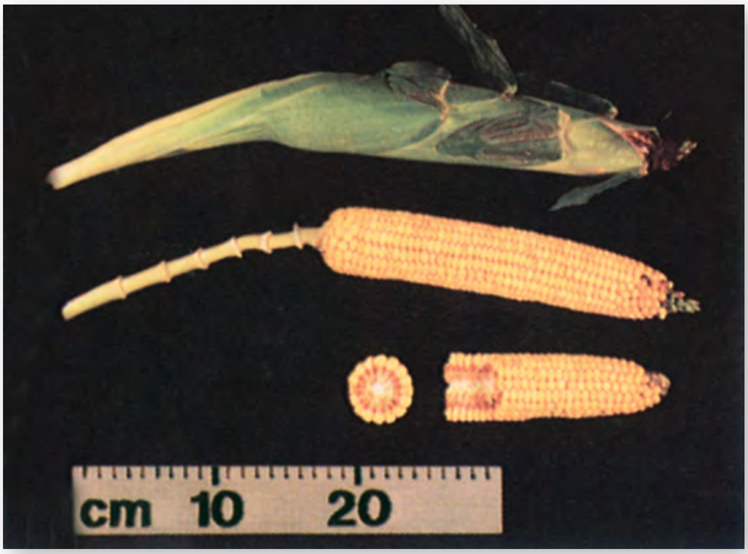


Figure 4–5. The R5 (dent) stage. Source: Ritchie et al. (1992)

Maturity and drying

Stage R6 (Physiological maturity)

By the end of the eighth week after pollination, the maize kernel has reached maximum dry weight.

At the tip of the kernel is a layer of tissue. It is this tissue which conducts sugar and other assimilates into the kernel. As the grain matures, the layer collapses, stops functioning, and turns black. The black layer indicates when the kernel has reached physiological maturity (stage R6) (Figure 4–7). An individual ear can be considered mature when 75% of the kernels in the central part of the cob have black layers.

The period from pollination to physiological maturity takes about 50 to 60 days.

The timing of harvest maturity of the ear depends entirely on moisture loss in order to reach a grain moisture level favourable for harvesting. Weather conditions at this time determine the rate of dry-down.

Factors affecting kernel development

Approximately 85% of grain yield is correlated with the number of kernels produced per hectare, with the remaining 15% being the weight of individual kernels.

Conditions during kernel development determine kernel size, whereas conditions in earlier growth stages mainly determine the number of ears and kernels per ear (Figure 4–8).

Understanding stress during kernel filling can help explain why cobs have aborted kernels or abnormal fill patterns (Figures 4–9 and 4–10) .

Moisture stress

The numbers of ears and number of kernels per ear are fixed soon after fertilisation. However, moisture stress, especially when coupled with high temperature, lack of nutrients, disease or

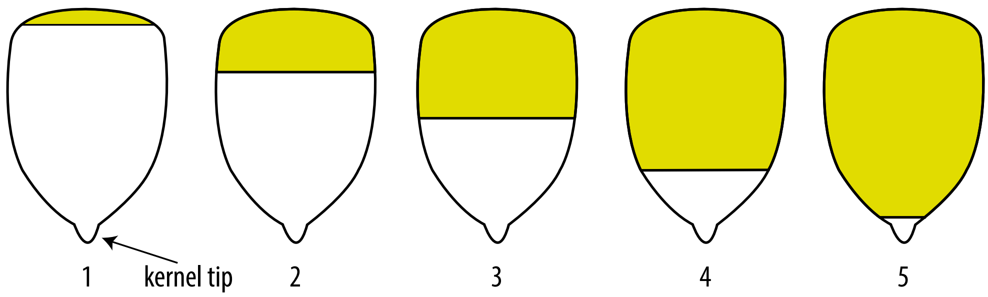


Figure 4–6. The receding milk line. Source: Colless (1992)

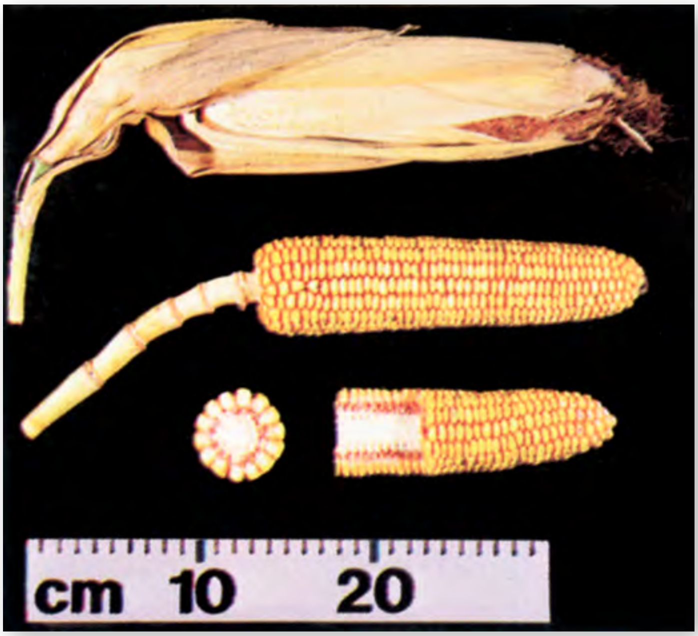


Figure 4–7. Stage R6 (physiological maturity). Source: Ritchie et al. (1992)

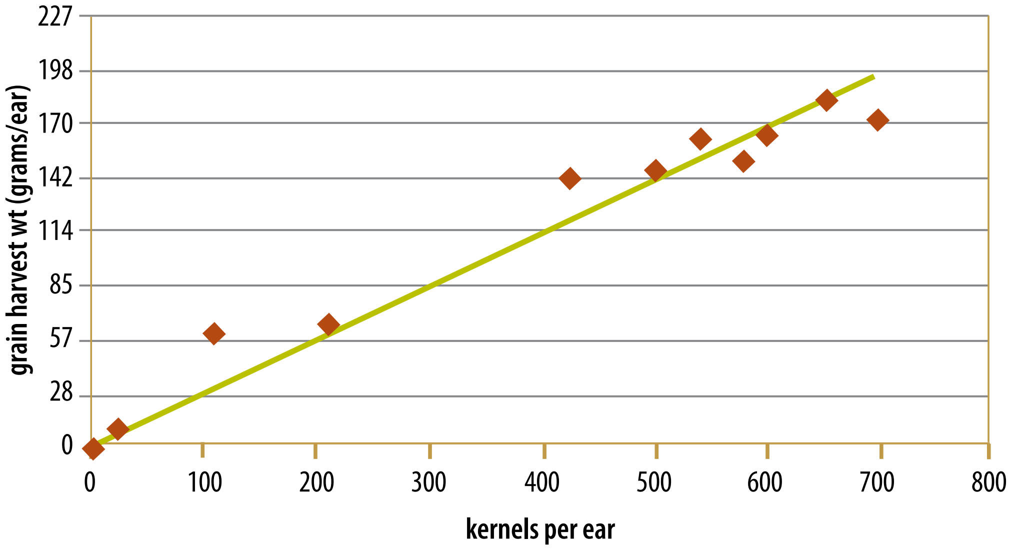


Figure 4–8. Grain yield per ear as a function of kernels per ear from the experiment in Figure 3–6. Source: Strachan (2001)

Figure 4–9. Environmental stress has reduced the width and length of the cob on the right. Photo: Kieran O'Keeffe

insect attack, will reduce kernel size and weight, and will determine whether tip kernels will fill even if they are pollinated.

In extreme cases of stress, the plant dies before the grain has reached full size. On the other hand, exceptionally favourable moisture conditions can result in better-than-expected kernel fill and give a higher grain yield.

When maize plants become moisture stressed, the lower parts of the plant wilt and suffer damage proportionately more than the upper parts.

With some hybrids, moisture stress slows the development of the silks much more than that of the tassel. This results in the pollen being spent before the silks emerge, and little or no grain is formed on the cobs. It is therefore important to select early-maturing hybrids in dryland or limited-irrigation situations.

Figure 4–11 is an example of the estimated daily water use. The tasselling to dough period is the period of peak water use and therefore very susceptible to moisture

Figure 4–10. Various stress factors can lead to missing kernels Source: Strachan (2001)

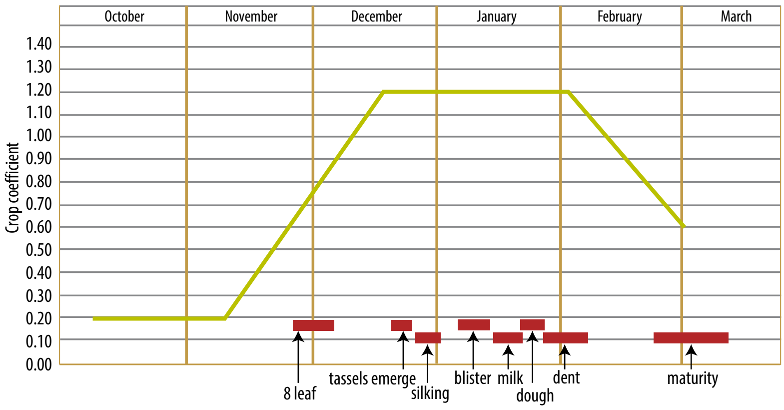
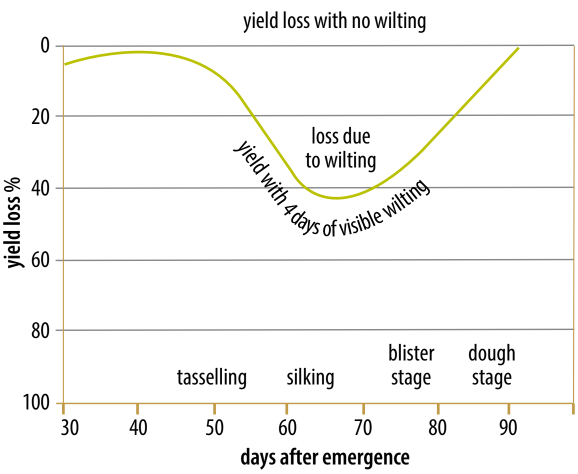


Figure 4–11. Crop coefficient curve used to estimate maize daily water use from evapotranspiration data. Based on a mid-October crop sown at Gunnedah. For use with pan evaporation data the coefficient should be multiplied by 0.8. Source: Australian Maize



- The maize crop coefficient can be estimated by walking through a crop on a sunny day in late morning or early afternoon. Make note of the percentage of shaded ground. Add 20% to the estimate and the result is the coefficient of the crop. For example, if 75% of the ground is shaded + 20%, then the crop coefficient is 95% or 0.95.

Figure 4–12. Yield loss due to wilting. Source: Colless (1992) stress. Within this period, the silking to blister stage is extremely critical. Consequently, if only one watering can be given, it should be applied just before tasselling.

Yield is generally lost when maize is visibly wilted for four consecutive days. Figure 4–12 shows the yield loss due to wilting at various stages.

Timing of the last irrigation

The final irrigation must be applied after the grain is well dented (usually milk line 2 or 3; see Figure 4–6), so there is ample soil moisture for the crop to completely fill the grain. If the crop suffers moisture stress during the last 10 to 14 days before maturity, yield is reduced by less than 1% a day, but this is still a significant loss if the stress persists for a number of days.

References and further reading

Colless JM, 1992. *Maize growing*, Agfact P3.3.3, second edition. NSW Department of Agriculture, Orange.

Kaiser A, Colless J, Lawson J, Nicholls C, 1997. *Australian Maize,* Kondinin Group, Redlands WA.

Ritchie S, Hanway J, Benson G, 1992. *How a Corn Plant Develops.* Special report no. 48, Iowa State University, Ames, Iowa. Retrieved from http://www.extension.iastate.edu/hancock/info/corn.htm on 25.6.08

Strachan SD, 2001. Crop insights. Corn grain yield in relation to stress during ear development. GRDC Irrigation update, Tocumwal, 2001, pp 31–38.

IN THE PADDOCK

Determining milk-line score

Aim: to identify the milk-line on the developing kernels

1. Randomly select 10 cobs from the crop.
2. Strip the husk from each cob and break it in two.
3. Retain the tip end of the cob.
4. Assess the average milk-line score from the exposed end of the cob (see Figure 4–6).

Estimating yield

Aim: to estimate yield in the paddock.

1. Yield estimates can be done from about 20 days after pollination (R3 or roasting ear stage).
2. Select a representative area of the paddock. An aerial image of the crop can be used to assess variability within the crop.
3. Count the number of ears in 10 m^2. If your crop is sown on 1 m rows, this will mean counting 10 m of row. Alternatively you can count 5 m of two adjacent rows.
4. Work out the number of kernels per ear by counting the number of rows in an ear and the number of kernels per row.
5. Steps 3 and 4 should be done at several sites in the paddock to get an accurate estimate.
6. Estimate the yield for each site by multiplying the number of ears by the average number of kernels per ear, multiplied by kernel weight (0.35 g).
7. The final result is multiplied by 1000 to get the yield for 10 000 m^2 or 1 ha.
8. Look at crop uniformity and adjust estimate.

$$\text{Yield (t/ha)} = \frac{\text{ears/ 10 m}^2 \text{ x number of kernels/ear x estimated kernel weight (g)}}{1000}$$

Worked example

$$\text{Yield (t/ha)} = \frac{50 \times 600 \times 0.35}{1000}$$

$$= 10.5 \text{ t/ha}$$

Calculating water-use efficiency

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

1. Using your rainfall records, calculate the amount of rainfall that was available to the crop during the growing period.
2. From irrigation records calculate the water supplied to the crop.
3. Using the total water supply (rainfall + amount of irrigation) and the yield, calculate WUE:

$$\text{WUE (kg/mm/ha)} = \frac{\text{crop yield (kg/ha)}}{\text{SSW + IW + Rf – RO}}$$

Where:

SSW = Soil-stored water prior to the first irrigation (with a full profile, allow 75 mm for red brown earth and 85 mm for a self-mulching grey clay).

IW = Irrigation water (1 ML/ha =100 mm).

Rf = Rainfall (mm).

RO = Re-used runoff (mm).

Typical WUE of maize is considered to be in the range of 13 to 15 kg of grain/mm/ha. With best practice agronomic management, good growing conditions and improved irrigation efficiencies, WUEs in maize have been recorded at over 20 kg/mm/ha.

Glossary

Allele

One member of a pair of genes.

Amylopectin

A glucose polymer that has a branched structure and is a component of starch.

Amylose

A glucose polymer that has a linear structure and is a component of starch. This type of starch is known as resistant starch and is used as a food additive to help prevent bowel cancer.

Apical meristem

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

Barren stalk

A stalk that because of early season stress does not produce an ear.

Black layer

A layer that develops at the tip (cob end) of the kernel and prevents further dry matter accumulation in the kernel. It appears soon after the milk line disappears, about 60 days after pollination. Most hybrids average about 30% moisture at the black layer stage.

Brace roots

Aerial roots that form at nodes just above the soil surface and extend down to reach the soil surface. They provide support plus extra access to soil moisture and mineral nutrition.

C_3 plant

Has a normal type of photosynthesis: carbon dioxide is first incorporated into a 3-carbon compound. Most plants are C_3 plants. Examples of C_3 plants are wheat, barley and oats.

C_4 plant

Has a specialised type of photosynthesis: carbon dioxide is first incorporated into a 4-carbon compound. C_4 plants carry out photosynthesis faster than C_3 plants under high light intensity and high temperatures. This gives better water use efficiency compared with that of C_3 plants at the same location, because the stomata (pores) are open for a shorter period of time.

Cob

A fully developed ear of maize.

Coleoptile

A protective cylindrical sheath-like structure that surrounds the first leaf.

Corn relative maturity (CRM)

Determination of maize maturity is based on the times from planting to silking, planting to physiological maturity and planting to harvest maturity.

CRM is an American system that has been used since 1939. It is also known as the 'Minnesota relative maturity system' and the 'comparative relative maturity system'. The system indicates the rate of maturity relative to a 'standard' hybrid. However, 'relative maturity' should not be confused with 'days to maturity'.

The system incorporates the influence of daylength on the rate of crop maturity. In Australia, CRM is of greatest relevance in southern latitudes (Tasmania, Victoria), equivalent to Minnesota, where the growing season is shorter (fewer warm days) and day length has greatest variation over the growing season.

Crown

The point where the plant's roots and vegetative parts join.

Dextrin

A short-chain starch molecule.

Ear

The developing cob structure of the maize plant.

Ear flex

The change in ear size that is related to plant population. If populations are too low, ear size is large but yield potential is not achieved.

Ear primordia

Also called ear shoots or initials, they form at each of the stem nodes up to the one forming a harvestable ear. Most hybrids produce a primordial ear at each of several stalk nodes, but only one or two will develop into a harvestable ear.

Embryo

Contains the main plant structures, so holds all the elements of the growing plant. It is made up of the scutellum, plumule (shoot) and radicale (primary root). The embryo is found at the end of the kernel that is attached to the cob.

Endosperm

A nutritive tissue within the seed that surrounds the embryo and provides energy for germination. The germinating seed relies on these reserves until it has developed a root system. The endosperm makes up the bulk of the grain and stores the starch and protein that are milled.

Fertilisation

The union of the male genetic material from the pollen with the female material in the ovule.

Filament

The stalk of a stamen.

Internode

Area of stalk between two nodes.

Leaf blade

Flat part of the leaf. The ligule (collar) is formed at the base of the leaf only after the entire leaf blade has been developed.

Leaf collar

The inner surface of the leaf where the blade and sheath join.

Leaf sheath

The leaf portion below the collar that wraps around a stalk and attaches the leaf to a stalk.

Leaf midrib

Extends along the length of the middle of the blade from base to tip. Lighter in colour and stronger than the rest of the leaf. The mid-vein provides structural support and exports sugars from the blade.

Meristematic dome

A dome of tissue located at the extreme tip of a shoot or ear.

Mesocotyl

The internode between the coleoptile node and the point where the stem and the root of the young seedling join.

Monoecious

A plant with both male and female flowers.

Mycotoxins

Toxins produced by certain moulds growing in the maize. They include aflatoxins and fumonisins.

Node

Stalk region slightly larger than that of the adjacent stalk internodes. Vascular bundles cross-connect at nodes, while vascular bundles are discretely separate within internodes.

Nodal roots

Extend directly from each node of the first several (at least six to eight) stalk nodes. These roots are the main sources of water and nutrients from about V3 through to maturity.

Ovule

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

Pericarp (seed coat)

The outer protective covering of the kernel.

Plumule

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

Polar nucleus

One of two nuclei located centrally in a flowering plant embryo sac that eventually fuse to form the endosperm nucleus.

Pollen

The male gametes, which are produced in the stamens.

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.

Radicle

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

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.

Seminal roots

Roots that grow directly from the kernel and serve as the principal source of water and also as an anchor for seedlings until about V3.

Stamen

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

Stover

Maize leaves and stalks that are left in the field after harvest.

Tassel

The male flowering structure of the maize plant.

Tiller

Extra stem coming from a node just above the soil surface. A tiller may bear a small ear but is generally non-productive.

Trichomes

Hair-like projections that extend from the main stem of the silk, much like root hairs extend from a plant root.

Whorl

Leaves that are not yet unfurled and remain wrapped together in a funnel-like shape. Leaves unfurl from the whorl as the stalk nodes that support them separate through internode elongation.

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