

# GROWNOTES™



## MAIZE

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[INSECT CONTROL](#)

[NEMATODE MANAGEMENT](#)

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# What's New

The GRDC GrowNotes are dynamic documents that are updated according to user feedback and newly available information.

This version of the GRDC Maize GrowNotes (updated April 2017) contains the following updates on original content published in December 2014:

## Section A – Introduction

Page xv

- New link: Research paper: A Greijdanus, M Kragt (2014) The grains industry: An overview of the Australian broad-acre cropping: <http://ageconsearch.umn.edu/bitstream/164256/2/WP1400002.pdf>

Page xxii

- New link: Maize yield determination in the Northern Region: Hybrid by environment by management interactions: <http://2015.agronomyconference.com/papers/agronomy2015final00193.pdf>
- New information: Tactical agronomy for dryland maize in the northern grains region. Presentation at 2016 Australian Summer Grains Conference, [http://yrd.com.au/ASG16\\_Program\\_Presentations\\_V5.pdf](http://yrd.com.au/ASG16_Program_Presentations_V5.pdf)

## Section 1 – Planning/Paddock Preparation

Page 1.3

- New information: Weed issues and action items: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Weed-issues-and-action-items>

Page 1.7

- New link: SoilWaterApp – a new tool to measure and monitor soil water: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/SoilWaterApp-a-new-tool-to-measure-and-monitor-soil-water>

Page 1.11

- New link: The impact of irrigation and nitrogen management on nitrogen uptake and yield in maize: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/The-impact-of-irrigation-and-nitrogen-management-on-nitrogen-uptake-and-yield-in-maize>

Page 1.12

- New link: Irrigation cropping - can we afford the water?: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Irrigation-cropping-can-we-afford-the-water>
- New link: Crop sequencing for irrigated double cropping within the Murrumbidgee Valley region: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Crop-sequencing-for-irrigated-double-cropping-Murrumbidgee-Valley-site>

Page 1.13

- New link: Increasing production with fast flow border check irrigation: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/03/Increasing-production-with-fast-flow-border-check-irrigation>

- New link: Automated irrigation in the palm of his hand: <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-122-May-Jun-2016/Automated-irrigation-in-the-palm-of-his-hand>

#### Page 1.28

- Updated link: Correct crop sequencing – Decision support tool: <http://www.dpi.nsw.gov.au/agriculture/budgets/costs/cost-calculators/correct-crop-sequencing-decision-support-tool>

#### Page 1.29

- New link: Crop sequencing for irrigated double cropping within the Murrumbidgee Valley region: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Crop-sequencing-for-irrigated-double-cropping-Murrumbidgee-Valley-site>
- New link: Double-cropping to absorb seasonal shocks: <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-127-March-April-2017/Double-cropping-to-absorb-seasonal-shocks>

## Section 2 – Pre-planting

#### Page 2.2

- Updated variety information

#### Page 2.6

- New information: Managing climate risk in rainfed maize with multi cobbing hybrids: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2017/03/Managing-climate-risk-in-rainfed-maize-with-multi-cobbing-hybrids>

## Section 5 – Nutrition and fertiliser

#### Page 5.1

- New section: Declining soil fertility

#### Page 5.11

- The what where and why of soil testing in the northern region: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/The-what-where-and-why-of-soil-testing-in-the-northern-region>

## Section 6 – Weed control

#### Page 6.6

- New information: Get the first second and third punch in on Feathertop Rhodes Grass: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Get-the-first-second-and-third-punch-in-on-Feathertop-Rhodes-Grass>

#### Page 6.7

- New link: Pre-emergent herbicides part of the solution but much still to learn: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Pre-emergent-herbicides-part-of-the-solution-but-much-still-to-learn>

#### Page 6.8

- New information: Recropping issues with pre emergent herbicides: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Recropping-issues-with-pre-emergent-herbicides>



## Section 7 – Insect control

### Page 7.1

- Weekly trap catch data for *H. punctigera* and *H. armigera* from locations across all states: <https://jamesmaino.shinyapps.io/MothTrapVis/>

### Page 7.8

- New information: Recent insect pest management research findings and the application of results in the field: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Recent-insect-pest-management-research-findings-and-the-application-of-results-in-the-field>

### Page 7.9

- New link: Scarab grubs in northern tableland pastures: [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0008/110213/scarab-grubs-in-northern-tableland-pastures.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0008/110213/scarab-grubs-in-northern-tableland-pastures.pdf)
- New link: Emerging insect threats in northern grain crops: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Emerging-insect-threats-in-northern-grain-crops>

## Section 8 – Nematode management

### Page 8.1

- GRDC Tips and Tactics: Root-Lesion Nematodes: <https://grdc.com.au/TT-RootLesionNematodes>

### Page 8.2

- New information: Summer cropping options to manage root lesion nematodes: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Summer-cropping-options-to-manage-root-lesion-nematodes>
- New information: Root-lesion nematodes. Northern Region: <http://www.grdc.com.au/TT-RootLesionNematodes>

## Section 9 – Diseases

### Page 9.1

- Where did the low levels of Fusarium head blight come from in 2016 and what does it mean: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2017/02/Where-did-the-low-levels-of-Fusarium-head-blight-come-from-in-2016-and-what-does-it-mean>

### Page 9.11

- New information: Close monitoring shows changing pathogen strains: <https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-116-Foliar-fungal-diseases-of-pulses-and-oilseeds/Close-monitoring-shows-changing-pathogen-strains>
- New link: Disease control in summer crops and management strategies to minimise financial losses: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Disease-control-in-summer-crops-and-management-strategies-to-minimise-financial-losses>

## Section 13 – Storage

### Page 13.1

- New link: Stored Grain Information Hub: <http://storedgrain.com.au/>
- New information: Part I Achieving great aeration results and Part II Silo recirculation as an aid to fumigation: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Part-I-Achieving-great-aeration-results-and-Part-II-Silo-recirculation-as-an-aid-to-fumigation>

#### Page 13.5

- New information: Part I Achieving great aeration results and Part II Silo recirculation as an aid to fumigation: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Part-I-Achieving-great-aeration-results-and-Part-II-Silo-recirculation-as-an-aid-to-fumigation>
- New link: Double croppers warm to maize expansion: <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-116-May-June-2015/Double-croppers-warm-to-maize-expansion>

#### Page 13.9

- Grain Storage Fact Sheet: Stored Grain Pests Identification: <http://www.grdc.com.au/GRDC-FS-StoredGrainPestID>

#### Page 13.10

- New information and figure: Grain protectants prevent pests: <http://www.grdc.com.au/GRDC-FS-GrainStoragePestControl>

#### Page 13.12

- New information, table and figure: GRDC (2014) Grain fumigation — a guide: <http://www.grdc.com.au/GRDC-FS-GrainFumigationGuide>

#### Page 13.14

- New information: Effective phosphine fumigation takes time: <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-119-Nov-Dec-2015/Effective-phosphine-fumigation-takes-time>

#### Page 13.15

- New information: What alternative fumigants are available?: <http://storedgrain.com.au/what-alternative-fumigants-are-available/>

#### Page 13.12

- New link: Phosphine alternatives still a stored grain protection goal: <https://grdc.com.au/Media-Centre/Ground-Cover/GroundCover-issue-127-MarchApril-2017/Phosphine-alternatives-still-a-stored-grain-protection-goal>
- New link: GRDC Grain Industry Guide: Fumigating with phosphine, other fumigants and controlled atmospheres. Do it right—do it once: [http://storedgrain.com.au/wp-content/uploads/2016/10/GRDC-PHOSP-Booklet\\_2016\\_R2\\_Reduced.pdf](http://storedgrain.com.au/wp-content/uploads/2016/10/GRDC-PHOSP-Booklet_2016_R2_Reduced.pdf)
- New link: Killing storage pests without mercy: <http://storedgrain.com.au/killing-storage-pests-without-mercy/>
- New link: New podcast: Phosphine resistance: <https://grdc.com.au/Media-Centre/GRDC-Podcasts/Driving-Agronomy-Podcasts/2015/11/Phosphine-Resistance>

## Section 14 – Environmental issues

#### Page 14.3

- New information: Managing frost risk. Northern, Southern and Western Regions. GRDC Tips and Tactics: <http://www.grdc.com.au/ManagingFrostRisk>
- New information: An analysis of frost impact plus guidelines to reduce frost risk and assess frost damage: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/An-analysis-of-frost-impact-plus-guidelines-to-reduce-frost-risk-and-assess-frost-damage>

## Section 15 – Marketing

#### Page 15.1

- Market research lifts export ambitions: <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-119-Nov-Dec-2015/Market-research-lifts-export-ambitions>

# Contents

## What's New

### Introduction

A.1	Management at a glance .....	xv
A.1.1	Profitability .....	xvi
A.2	Crop overview.....	xvii
A.2.1	Production.....	xix
A.3	Maize types .....	xx
A.3.1	Maize for processing .....	xxii
A.3.2	Maize for stockfeed .....	xxii
A.4	Current research in northern NSW and Queensland .....	xxii

## 1 Planning/Paddock preparation

1.1	Paddock selection.....	2
1.1.1	Soil types.....	2
1.2	Paddock rotation and history.....	3
1.3	Maize in crop rotations.....	3
1.3.1	In rotation with cotton.....	4
1.3.2	Pest and disease impacts .....	5
1.4	Fallow weed control.....	5
1.5	Seedbed requirements.....	6
1.6	Soil moisture.....	7
1.6.1	Water requirements.....	7
1.6.2	Crop water use .....	8
1.6.3	Modification of agronomy to improve WUE.....	9
<i>Planting date</i> .....	9	
<i>Planting geometry</i> .....	9	
<i>Tillage</i> .....	9	
<i>Residue retention and plastic mulch</i> .....	9	
<i>Weed control and fertiliser use</i> .....	10	
<i>Irrigation management</i> .....	10	
1.6.4	Irrigation.....	11
<i>Water budgeting</i> .....	12	
<i>Types of irrigation</i> .....	12	
<i>Peak water use</i> .....	13	
<i>Scheduling irrigations</i> .....	13	
<i>Timing the first irrigation</i> .....	14	

	<i>Irrigation scheduling tools</i> .....	14
	<i>Impacts of stress</i> .....	14
	<i>Timing the last irrigation</i> .....	15
	<i>Scheduling supplementary irrigation</i> .....	15
1.6.5	Optimising maize yield under irrigation .....	16
1.6.6	How much water is needed to optimise maize yield? .....	18
1.6.7	Some local data.....	22
1.6.8	Irrigation in Queensland.....	23
<b>1.7</b>	<b>Yield and targets</b> .....	<b>23</b>
1.7.1	Seasonal outlook .....	25
1.7.2	Water Use Efficiency .....	26
1.7.3	Nitrogen-use efficiency .....	28
1.7.4	Double-crop options .....	28
1.7.5	What is relay cropping? .....	29
<b>1.8</b>	<b>Relay cropping extends cropping window</b> .....	<b>30</b>
	<i>Could the relay-cropping systems from the Argentine Pampas open a new frontier for the northern grains industry?</i> .....	30
1.8.1	Constraints.....	31
1.8.2	Opportunity.....	32
<b>1.9</b>	<b>Nematode status of paddock</b> .....	<b>32</b>
1.9.1	Nematode testing of soil.....	32
1.9.2	Effects of cropping history on nematode status.....	33
<b>1.10</b>	<b>Insect status of paddock</b> .....	<b>33</b>
1.10.1	Soil sampling for insects .....	34
	<i>Soil sampling by spade</i> .....	34
	<i>Germinating-seed bait technique</i> .....	35
	<i>Detecting soil-dwelling insects</i> .....	35
<b>2</b>	<b>Pre-planting</b>	
<b>2.1</b>	<b>Selecting maize varieties</b> .....	<b>1</b>
<b>2.2</b>	<b>Maize variety characteristics</b> .....	<b>2</b>
2.2.1	Maturity .....	4
2.2.2	Time to flowering .....	4
2.2.3	Adaptability.....	5
2.2.4	Cob height .....	5
2.2.5	Husk cover.....	5
2.2.6	Standability .....	5
2.2.7	End use.....	6
2.2.8	Isolation .....	6
2.2.9	Tillers .....	6
2.2.10	Multi cobbing hybrids.....	6
2.2.11	The final decision—which variety? .....	8

<b>2.3</b>	<b>Planting seed quality .....</b>	<b>8</b>
2.3.1	Seed size.....	9
2.3.2	Safe rates of fertiliser sown with the seed .....	9
<b>3</b>	<b>Planting</b>	
<b>3.1</b>	<b>Seed treatments .....</b>	<b>1</b>
<b>3.2</b>	<b>Soil type .....</b>	<b>1</b>
<b>3.3</b>	<b>Time of sowing.....</b>	<b>2</b>
3.3.1	Soil temperature.....	2
3.3.2	Planting moisture requirement.....	4
3.3.3	New South Wales.....	4
3.3.4	Queensland .....	4
<b>3.4</b>	<b>Targeted plant population .....</b>	<b>5</b>
3.4.1	Plant populations .....	5
3.4.2	Planting rate .....	7
3.4.3	Row spacing .....	8
<b>3.5</b>	<b>Sowing depth .....</b>	<b>9</b>
<b>3.6</b>	<b>Sowing equipment .....</b>	<b>9</b>
3.6.1	Evenness of establishment.....	10
<b>4</b>	<b>Plant growth and physiology</b>	
<b>4.1</b>	<b>Germination and emergence .....</b>	<b>2</b>
4.1.1	Germination—VE stage.....	2
4.1.2	Emergence—VE stage .....	4
4.1.3	Factors affecting germination and emergence.....	5
	<i>Moisture.....</i>	<i>5</i>
	<i>Waterlogging .....</i>	<i>5</i>
	<i>Temperature.....</i>	<i>5</i>
	<i>Oxygen .....</i>	<i>6</i>
	<i>Nutrition .....</i>	<i>7</i>
	<i>Seedbed.....</i>	<i>7</i>
	<i>Sowing depth.....</i>	<i>8</i>
	<i>Plant population.....</i>	<i>8</i>
<b>4.2</b>	<b>Vegetative growth.....</b>	<b>10</b>
4.2.1	Vegetative Growth.....	10
	<i>V1–V2 stage .....</i>	<i>10</i>
	<i>V3–V5 stages.....</i>	<i>10</i>
	<i>Ear initiation.....</i>	<i>11</i>
	<i>Establishing the number of kernel rows around the ear (V5–V8 stage).....</i>	<i>12</i>
	<i>V6 and V7 stages.....</i>	<i>12</i>
	<i>Establishing kernel numbers (V7–pollination).....</i>	<i>13</i>
	<i>V8 and V9 stages.....</i>	<i>14</i>
	<i>V10 and V11 stages.....</i>	<i>15</i>
	<i>V12 and V13 stages.....</i>	<i>16</i>





<i>V14 and V15 stages</i> .....	17
<i>V16 and V17 stages</i> .....	18
<i>V18 or VT stage</i> .....	18
<b>4.2.2 Factors affecting vegetative growth</b> .....	<b>19</b>
<i>Moisture</i> .....	19
<i>Irrigation</i> .....	20
<i>Nutrition</i> .....	23
<b>4.3 Reproductive development</b> .....	<b>27</b>
<b>4.3.1 Stages</b> .....	<b>27</b>
<i>Tasselling–VT</i> .....	27
<i>Flowering (pollen shed and silking)–R1</i> .....	28
<b>4.3.2 Factors affecting reproductive development</b> .....	<b>30</b>
<i>Moisture stress</i> .....	30
<i>Temperature</i> .....	32
<i>Assimilate supply</i> .....	33
<i>Competition from other plant parts</i> .....	33
<b>4.4 Kernel development</b> .....	<b>34</b>
<b>4.4.1 Stages</b> .....	<b>34</b>
<i>R2 (blister stage)</i> .....	34
<i>R3 (milk stage)</i> .....	35
<i>R4 (dough stage)</i> .....	35
<i>R5 (dent stage)</i> .....	36
<b>4.4.2 Maturity and drying</b> .....	<b>37</b>
<i>Stage R6 (physiological maturity)</i> .....	37
<i>Factors affecting kernel development</i> .....	38
<i>Moisture stress</i> .....	40
<b>4.4.3 References and further reading</b> .....	<b>41</b>
<b>5 Nutrition and fertiliser</b>	
<b>5.1 Declining soil fertility</b> .....	<b>1</b>
5.1.1 <i>Soil organic matter</i> .....	1
5.1.2 <i>Current situation</i> .....	4
5.1.3 <i>Options for reversing the decline in soil organic matter</i> .....	5
<i>Impact of fertiliser N inputs on soil</i> .....	7
<b>5.2 Nutrition</b> .....	<b>7</b>
<b>5.3 Soil fertility</b> .....	<b>10</b>
<b>5.4 Soil testing</b> .....	<b>11</b>
<b>5.5 Key nutrients</b> .....	<b>11</b>
<b>5.6 Animal manure</b> .....	<b>14</b>
<b>5.7 Crop removal rates</b> .....	<b>15</b>
<b>5.8 Nitrogen</b> .....	<b>15</b>
<b>5.9 Phosphorus</b> .....	<b>17</b>
<b>5.10 Sulfur</b> .....	<b>18</b>
<b>5.11 Potassium</b> .....	<b>18</b>

5.12 Long-fallow disorder ..... 20

5.13 Micronutrients ..... 20

    5.13.1 Zinc ..... 20

    5.13.2 Molybdenum ..... 22

    5.13.3 Magnesium ..... 22

**6 Weed control**

6.1 Competition from weeds ..... 1

6.2 Main weed species of concern in maize crops ..... 2

6.3 Forms of weed control ..... 5

    6.3.1 Mechanical weed control ..... 5

    6.3.2 Mechanical and chemical weed control ..... 5

    6.3.3 Chemical weed control ..... 5

6.4 Farm hygiene ..... 5

6.5 Crop rotation ..... 6

6.6 Maize growth stages ..... 6

6.7 Pre-emergent herbicides ..... 7

    6.7.1 Recropping issues with pre-emergent herbicides ..... 8

6.8 Post-plant pre-emergent herbicides ..... 8

    6.8.1 Imidiazolinone technology ..... 8

6.9 Potential herbicide damage effect ..... 9

**7 Insect control**

7.1 Maize pests by crop stage ..... 1

7.2 Early pests ..... 2

    7.2.1 Mice ..... 2

7.3 Soil insects ..... 3

    7.3.1 Monitoring for soil insects ..... 3

    7.3.2 Black field earwig ..... 4

    7.3.3 True wireworm ..... 5

    7.3.4 False wireworm ..... 6

    7.3.5 Cutworm ..... 7

    7.3.6 Scarab larvae ..... 8

*Damaging densities* ..... 8

7.4 Pests of the vegetative stage ..... 9

    7.4.1 Maize leafhoppers ..... 9

    7.4.2 Maize thrips ..... 10

    7.4.3 Corn aphid ..... 11

    7.4.4 Podsucking or shield bugs ..... 12

    7.4.5 Locusts ..... 13

*Whitefringed weevil* ..... 14

    7.4.6 Redshouldered leaf beetle ..... 14

7.4.7	Swarming leaf beetles .....	14
7.4.8	Armyworms.....	14
<b>7.5</b>	<b>Silking–tasseling-stage pests .....</b>	<b>16</b>
7.5.1	Corn earworm .....	16
<b>7.6</b>	<b>Pests of the grainfill stage .....</b>	<b>17</b>
7.6.1	Two-spotted mite .....	17
7.6.2	Yellow peach moth .....	17
<b>8</b>	<b>Nematode management</b>	
8.1	Nematode testing of soil.....	1
8.2	Effects of cropping history on nematode status .....	1
8.3	Using rotations including maize to manage nematodes .....	2
<b>9</b>	<b>Diseases</b>	
9.1	Diseases of a developing and mature maize plant.....	1
9.1.1	Seed rots and seedling blights .....	2
9.1.2	Stalk and root rot diseases.....	2
	<i>Fusarium stalk rot (caused by Fusarium verticillioides [Gibberella fujikuroi] and other Fusarium species).....</i>	<i>3</i>
	<i>Gibberella stalk rot (caused by Gibberella zeae; Fusarium graminearum).....</i>	<i>3</i>
9.1.3	Ear and kernel rots.....	3
	<i>Fusarium cob rot or ear rot (Fusarium verticillioides and other Fusarium species)....</i>	<i>4</i>
	<i>Gibberella cob rot, ear rot or pink ear rot (caused by Gibberella zeae; Fusarium graminearum).....</i>	<i>4</i>
	<i>Diplodia cob rot or ear rot (caused by Diplodia spp.).....</i>	<i>4</i>
9.1.4	Blights .....	5
	<i>Turcica leaf blight or turcicum leaf blight (caused by Exserohilum turcicum) .....</i>	<i>5</i>
	<i>Maydis leaf blight (caused by Bipolaris maydis).....</i>	<i>5</i>
9.2	Rusts .....	5
9.2.1	Common rust (caused by <i>Puccinia sorghi</i> ).....	6
9.2.2	Polysora rust or tropical rust or southern maize rust (caused by <i>Puccinia polysora</i> ).....	6
9.3	Smuts.....	6
9.3.1	Boil smut or common smut (caused by <i>Ustilago zeae</i> , formerly known as <i>U. maydis</i> ).....	6
9.3.2	Head smut (caused by <i>Sporisorium reilianum</i> ) .....	7
9.4	Wallaby ear .....	7
9.5	Viruses.....	8
9.5.1	Johnson grass mosaic virus .....	8
9.5.2	Maize dwarf mosaic virus .....	8
9.6	Rots of stored grain.....	8
9.7	Mycotoxins and mycotoxicoses .....	9
9.8	Summer crops as host species.....	11

**10 Plant growth regulators and canopy management**

**11 Crop desiccation/spray out**

**12 Harvest**

12.1 Timing ..... 1

12.2 Grain for milling markets ..... 2

12.3 Black layer or physiological maturity..... 2

**13 Storage**

13.1 How to store maize on-farm..... 2

13.2 Aeration during storage..... 5

13.3 Hygiene ..... 8

13.4 Monitoring grain ..... 9

13.5 Grain protectants and fumigants.....10

    13.5.1 Grain protectants ..... 10

*Pest prevention*.....10

*Read the label*..... 11

*Close to MRL*..... 11

*Accurate application*..... 11

    13.5.2 Grain fumigation ..... 12

*Rates for success*.....12

*Handle with care* .....12

*Where to apply*.....13

*Time to kill*.....13

*Gas venting* .....13

*Phosphine resistance* ..... 14

*What alternative fumigants are available?*..... 15

**14 Environmental issues**

14.1 Frost issues ..... 1

    14.1.1 Conditions causing frost damage..... 1

    14.1.2 Assessing frost damage .....1

    14.1.3 Risk management for frost ..... 3

    14.1.4 The changing nature of frost in Australia ..... 3

14.2 Waterlogging and flooding issues ..... 3

    14.2.1 Effects on the maize root system..... 4

**15 Marketing**

15.1 Preventing mycotoxin contamination ..... 2

15.2 Marketing ..... 2

    15.2.1 Grain .....2

    15.2.2 Marketing silage .....2

    15.2.3 Drying corn for the gritting millers.....2

15.3 Maize Association of Australia (MAA) ..... 3

[TABLE OF CONTENTS](#)

[FEEDBACK](#)

**16 Current research**

**17 References**



# Introduction

## A.1 Management at a glance

Organise marketing contracts before planting. Growers should discuss specific quality requirements with end users when negotiating contracts (Figure 1). Market sectors for human consumption have strict specifications. New or prospective growers should use the [Maize Association of Australia](#) website to connect with buyers looking for maize. Growers should be aware that, on occasion, only specific varieties are contracted; therefore, conflicts may arise with regard to varietal choice and agronomic performance.

### Key points

- Plant hybrids that have the desired characteristics for your conditions.
- Plant at the optimum time to avoid early frosts, extreme heat at flowering, and a cool, slow dry-down.
- Set a target yield based on moisture availability and match inputs to the target. Maize is less tolerant of moisture stress than other summer crops such as grain sorghum.
- Plant inland dryland crops when there is at least 1 m depth of wet soil.
- For irrigated crops, calculate water budgets, matching the crop area to water allocation. Do not stretch irrigation intervals in order to increase crop area, in particular from just prior to tasselling to the start of the milk-line stage.
- Always use press-wheels at planting.
- Adjust plant population and row spacing according to the target yield.
- Apply nitrogen, phosphorus and potassium fertiliser based on target yields, soil tests and/or previous crop yields.
- Use controlled-traffic farming with no-till to reduce soil compaction (maize is relatively susceptible to compaction), improve moisture storage and reduce fuel costs.<sup>1</sup>
- Plan and implement an effective weed management strategy prior to planting.
- Long fallow disorder in maize can severely limit the crop.

### MORE INFORMATION

A general summary of the Australian grain growing regions is available at A Greijdanus, M Kragt (2014) [The grains industry: An overview of the Australian broad-acre cropping](#)

### MORE INFORMATION

[Maize Association of Australia](#)

<sup>1</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>



**Figure 1:** Organise marketing contracts before planting to ensure that specifications are met for human consumption market sectors.

### A.1.1 Profitability

Many growers assume that the highest yielding crops are the most profitable. There is a perception that increasing inputs such as fertiliser and water will automatically lead to greater yields and, hence, more profit per hectare.

However, increasing inputs to maximum levels does not always lead to greater yields and a better profit margin. The highest yielding, competition-winning crop may attract a lot of interest but it may not be as profitable as a lower yielding crop that is well managed.

Rapid advances in plant breeding technology, plant protection and management expertise over the last decade have resulted in significant increases in the yield potential and stress tolerance of maize. For many farmers producing maize as a grain crop or for silage production, potential exists to increase profits. Several important factors will contribute to this. For irrigation farmers, water management is key.

The yield potential of maize will vary among districts and farms because of water availability, altitude, sunlight, soil structure and soil fertility. Yield potential will also vary between seasons at the same site depending on seasonal conditions (e.g. heat wave, drought) as well as choice of hybrid and sowing time.

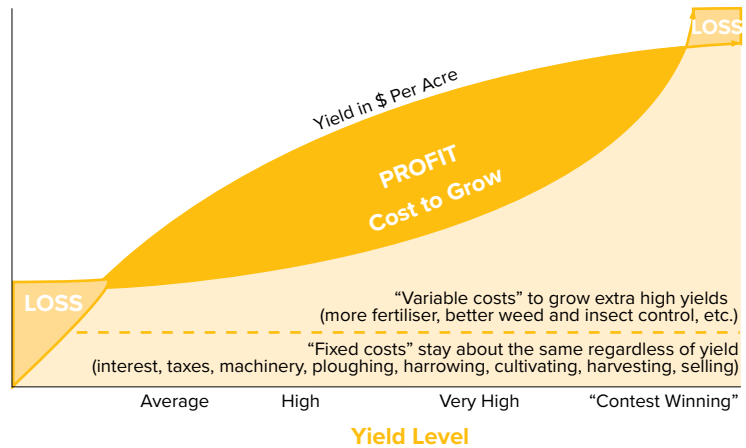
The most profitable maize crop is obtained by optimising (rather than maximising) key inputs such as seed, fertiliser and water, and the timing of these inputs as shown in Figure 2.

Many farmers underestimate the effect of yield on profit, equating a 10% increase in yield with a 10% increase in profit. The real increase in profit may be 50% or even 100%. This is because many costs, such as cultivation, planting and spraying remain the same for all yield levels.

Important steps towards a profitable maize crop are:

- determining the market you intend to supply
- understanding the requirements of the crop
- setting a yield goal for each field
- planting suitable hybrids at the correct plant populations
- providing adequate fertiliser and water at the critical growing stages
- growing only an area you can manage. <sup>2</sup>

<sup>2</sup> Pioneer Hi-Bred Australia. Growth potential. Corn Growers' Workshop. [http://www.pioneer.com/CMRoot/International/Australia\\_Intl/Publications/Corn\\_Workshop\\_Book.pdf](http://www.pioneer.com/CMRoot/International/Australia_Intl/Publications/Corn_Workshop_Book.pdf)



**Figure 2:** Timing of key inputs for growing a profitable crop.

Source: Pioneer

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[Growth potential. Corn Growers' Workshop. Pioneer Hi-Bred Australia.](#)

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[Maize Association of Australia](#)

[Commodity growing guides—sweet corn. NSW Department of Primary Industries.](#)

[Australian maize industry overview—2012. Grains Research and Development Corporation.](#)

## A.2 Crop overview

Maize is a multipurpose, summer, cereal, grain and silage crop that serves as a good rotation crop with legumes and cotton. Maize has a low capital investment, low growing risk and generally a longer window of harvest than other crops. The industry is valued at AU\$25–35 million annually, depending on prices, area planted and yields.<sup>3</sup>

In Australia maize is a minor summer crop with an annual production of 350,000–450,000 tonnes (t), historically most of which is consumed domestically (Figure 3). However, with the help of the Maize Association of Australia, the peak body representing Australian maize growers and the industry at large, a new export market has been opened up to farmers and traders. Maize produced in Australia is approximately 50% rainfed or dryland and 50% grown with the assistance of irrigation. All Australian maize is non-genetically modified organism (non-GMO).

Maize grain varies greatly from very soft (starchy) to very hard (hard endosperm), which determines end use.

<sup>3</sup> QDAF (2012) Maize production in Queensland. Department of Agriculture, Fisheries and Forestry Queensland. <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize>





**Figure 3:** Australia is developing export markets for maize.

Photo: Pacific Seeds

‘Flint corn’ (*Zea mays var. indurata*, also known as Indian corn or calico corn) is a variant of maize (*Zea mays* L.). Because each kernel has a hard outer layer to protect the soft endosperm, it is likened to being ‘as hard as flint’.<sup>4</sup>

‘Dent corn’ (var. *indentata*) also known as ‘yellow dent corn’, ‘Reid’s yellow dent corn’, ‘white dent corn’ or ‘field corn’ is a variety of maize with a high soft-starch content. It received its name because of the small indentation (‘dent’) at the crown of each kernel on a ripe ear of corn.<sup>5</sup>

Grown under the same conditions, the highest protein would be expected in quick flint, followed by med-slow flint, quick dent and the lowest in med-slow dent (Table 1).<sup>6</sup>

Two types of starch can be contained in maize. Regular yellow maize and white maize contain approximately 73% amylopectin and 27% amylose. Waxy maize produces 100% amylopectin. Hi-amylose can be up to 80–90% amylose and 10–20% amylopectin.

The industry delivery standard and a safe storage level is 14% moisture content.<sup>7</sup>

**i MORE INFORMATION**

Harvesting and production of sweet corn. Industry overview. Department of Agriculture, Fisheries and Forestry Queensland.

4 Flint corn. Wikipedia, [http://en.wikipedia.org/wiki/Flint\\_corn](http://en.wikipedia.org/wiki/Flint_corn)

5 Dent corn. Wikipedia, [http://en.wikipedia.org/wiki/Dent\\_corn](http://en.wikipedia.org/wiki/Dent_corn)

6 Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

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**Table 1:** Typical analysis of flint and dent types on a dry basis.

	Flint	Dent
Starch content (%)	66.5	72.0
Protein content (%)	13.5	10.0
Oil content (%)	6.0	5.0
Fibre content (%)	14.0	143.0

Source: Pacific Seeds

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 human foods, animal feeds, and the manufacture of pharmaceutical and industrial products. It is the staple food source for people in many countries. Maize is highly desirable as an animal feed because of the high energy and feed value of the kernel, leaf and stem. It is 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 C4 (tropical) plant. It uses carbon dioxide, solar radiation, water and nitrogen more efficiently during photosynthesis than C3 (temperate) crops. The Water Use Efficiency of maize is approximately double that of C3 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. Most plants are C3 plants, including wheat, barley and oats.

C4 plants have a specialised type of photosynthesis whereby carbon dioxide is first incorporated into a 4-carbon compound. C4 plants carry out photosynthesis faster than C3 plants under high light intensity and high temperatures. This gives better Water Use Efficiency than that of C3 plants at the same location, because the stomata (pores) are open for a shorter period.

**C3 plant.** Has a normal type of photosynthesis: carbon dioxide is first incorporated into a 3-carbon compound. Most plants are C3 plants. Examples of C3 plants are wheat, barley and oats.

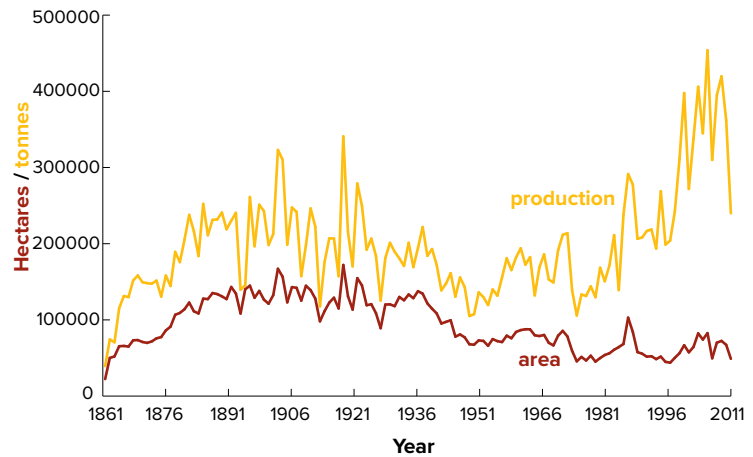
**C4 plant.** Has a specialised type of photosynthesis: carbon dioxide is first incorporated into a 4-carbon compound. C4 plants carry out photosynthesis faster than C3 plants under high light intensity and high temperatures. This gives better Water Use Efficiency than that of C3 plants at the same location, because the stomata (pores) are open for a shorter period.

## A.2.1 Production

Total maize production in Australia in 2009 was 255,000 t, covering an area of 49,000 ha. For production, the historical high was in 2002 at 454,000 t, and for area, it was in 1924 at 172,000 ha. Since 1924, the area under cultivation for maize has steadily declined, whereas production increased notably from the early 1980s (Figure 4).<sup>8</sup>

<sup>8</sup> Australian Bureau of Statistics (2013) Historical Selected Agriculture Commodities, by State (1861 to Present), (cat. no. 7124.0). Australian Bureau of Statistics, <http://www.abs.gov.au/AUSSTATS/abs@.nsf/mf/7124.0>





**Figure 4:** Maize production and area in Australia.

Source: ABS

Temperature and available moisture determine where maize is grown in NSW. Production areas include the North Coast, Liverpool Plains, and Northwest Slopes and Plains. In these areas, the crop grows best in deep, well-drained, fertile soils.

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

The average area of maize grown in NSW from 1998 to 2007 was 26,944 ha, producing 211,681 t of grain.<sup>9</sup>

In 2012–13, 34,000 ha was planted to maize for grain in NSW, producing 261,232 t at an average yield of 7.7 t/ha. In Queensland for this period, 40,208 ha produced 213,117 t at an average yield of 5.3 t/ha.<sup>10</sup> The main maize-growing areas in Queensland include the Darling Downs, Central Highlands and Burdekin Irrigation Area.

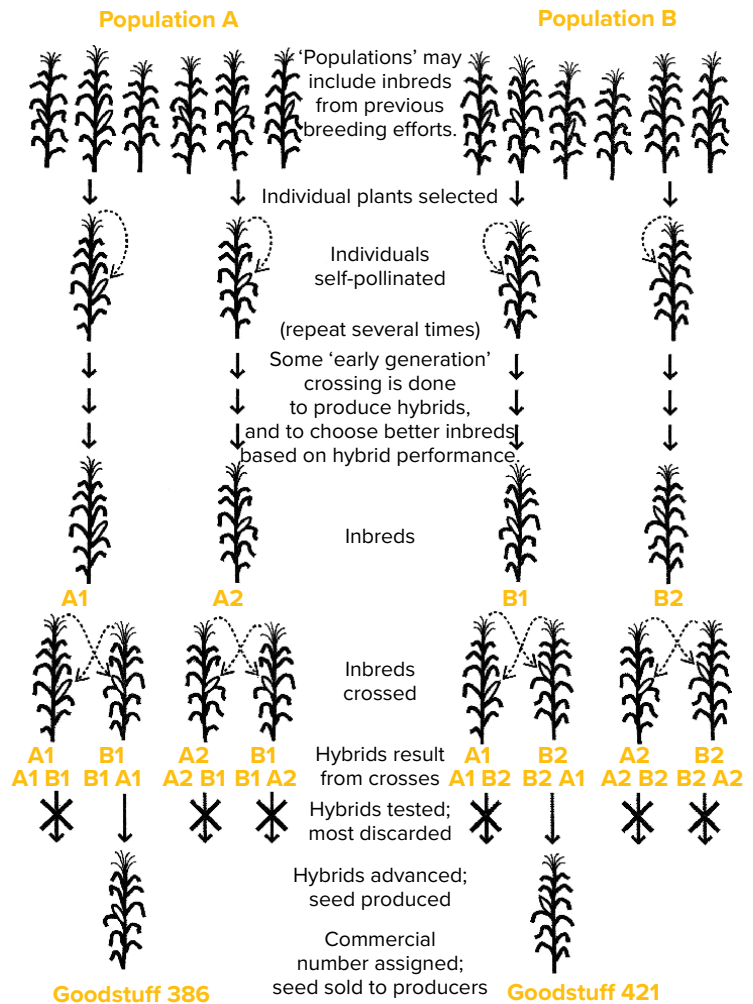
### A.3 Maize types

Almost all maize in NSW and Queensland 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 5). This hybrid has two alleles (an allele is an alternative form of a gene), one contributed by each parent. One allele is usually dominant and the other recessive. The F1 generation individuals are all similar.

<sup>9</sup> Australian Bureau of Statistics (2013) Historical Selected Agriculture Commodities, by State (1861 to Present), (cat. no. 7124.0). Australian Bureau of Statistics, <http://www.abs.gov.au/AUSSTATS/abs@nsf/mf/7124.0>

<sup>10</sup> Australian Bureau of Statistics (2014) 7121.0 - Agricultural Commodities, Australia and 7503.0 - Value of Agricultural Commodities Produced, Australian Bureau of Statistics, <http://www.abs.gov.au/AUSSTATS/abs@nsf/DetailsPage/7121.02012-2013?OpenDocument> and <http://www.abs.gov.au/AUSSTATS/abs@nsf/mf/7503.0>



**Figure 5:** Example of a breeding scheme for maize, showing how hybrids are produced.<sup>11</sup>

Source: Hoelt et al. 2000

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.<sup>12</sup>

<sup>11</sup> K. O'Keefe (2009) Maize growth and development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)

<sup>12</sup> QDAF (2012) Maize production in Queensland. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize>

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CJ Birch *et al.* (2003) Agronomy of maize in Australia: in review and prospect. In 5th Australian Maize Conference.

**i MORE INFORMATION**

Maize yield determination in the Northern Region: Hybrid by environment by management interactions

### A.3.1 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 such as corn flour.

If the grain is to be processed, the grower must select hybrids that are recommended by the particular manufacturer, because they will not accept other hybrids.<sup>13</sup>

### A.3.2 Maize for stockfeed

Varieties used for stockfeed are chosen mainly for their yield potential rather than grain quality. Growers will need storage facilities if growing feed maize, to cater for buyers demanding supply throughout the year.

## A.4 Current research in northern NSW and Queensland

Research underway in northern NSW and Queensland, as part of the Tactical Sorghum and Maize Agronomy project, aims to develop a base dataset to support renewed grower and advisor confidence in reliably producing rainfed maize in this region.

Three main aspects are being trialled:

- hybrid selection—including maturity and degree of prolificacy i.e. the ability of a hybrid to produce multiple cobs per plant
- plant populations for dryland maize—15–50,000 plants/ha
- row configuration—solid, single skip or superwide.

Results thus far from NSW indicate that:

- dryland maize west of the Newell highway is a challenge due to the high temperatures
- plant populations of 15–30,000 plants/ha look promising (50,000 plants/ha produces lower yields and higher lodging)
- row configurations of single skip or superwide appear to be viable options for Moree and Liverpool Plains
- number of cobs per plant is only part of the story; it is unclear yet whether higher tillering and more cobs per plant will produce the highest yields
- in most seasons, growers can produce between 2–5 t/ha dryland maize in northern NSW
- price per tonne will drive profitability.<sup>14</sup>

<sup>13</sup> QDAF (2012) Maize production in Queensland. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize>

<sup>14</sup> L Serafin (2016) Tactical agronomy for dryland maize in the northern grains region. Presentation at 2016 Australian Summer Grains Conference, [http://yrd.com.au/ASG16/Program\\_Presentations\\_V5.pdf](http://yrd.com.au/ASG16/Program_Presentations_V5.pdf)

# Planning/Paddock preparation

Maize is a summer-growing, multipurpose cereal crop that needs warm (but not hot) daytime temperatures, mild nights and moist, well-drained soil to maximise yield. The growing season is usually 120–150 days from planting to harvest.

Maize is grown as both a dryland and an irrigated crop. A high-yielding crop uses up to 850 mm of water through evapotranspiration (ET) during the growing season. Along the coastal belt and in the tablelands, crops can usually be grown successfully without irrigation; however, supplementary irrigation will improve yields.

Maize can be grown to produce grain for a range of human food and stockfeed markets, or the whole plant can be harvested green for fodder or silage. Yield potentials are similar to those of sorghum, but with greater response to irrigation.<sup>1</sup>

The success of maize as a crop option throughout Australia in recent seasons has made it a viable option for many growers into the future.

Traditionally, maize has been a popular option only in certain geographic areas, but with advances in hybrid performance and agronomic techniques, the success of the crop in a variety of environments has increased. The success of maize is partly due to its versatility with regard to planting time and the various end-use options. Grain from various hybrids fills both feed and specialty processing markets, and the crop is commonly used to produce bulk tonnage of high-energy silage.

In areas such as Central Queensland, maize is often grown under dryland conditions in skip-row formations so that the plants can make the most of available moisture and nutrients and the seasonal conditions. Maize has some advantages over sorghum, which is more traditionally grown in the region; its natural senescence characteristics mean that it dies down at the end of its life cycle, so does not require spraying out with a herbicide or defoliant prior to harvest. It may be sown earlier and later than traditional sorghum crops, which adds flexibility to farming system.

Because of its annuality, maize often leaves residual moisture after senescence, allowing a double-crop opportunity for winter pulse crops or accumulated moisture for the following crop in the rotation.

With the wet conditions that can be a feature of the eastern states of Australia, the characteristic of senescence has allowed maize to sit through the deluge and, in many cases, be harvested when conditions improve.

Maize generally has advantages over other crops in its ability to resist weathering while awaiting harvest, partly due to husk cover parameters. Maize hybrids generally have a thick husk cover over the cob to protect the grain from adverse weather.

In areas such as southern Queensland and NSW, maize has become increasingly popular as both a dryland and an irrigation option. Although cotton is traditionally the main irrigation crop in those regions, maize has made significant inroads as a crop rotation or planting partner option.

On the upper Liverpool Plains, maize still provides healthy gross margins compared with cotton because of its ability to establish earlier in the season, return a better yield per megalitre of irrigation, and senesce and harvest well before cotton can be defoliated and picked.

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<sup>1</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

## SECTION 1 MAIZE

TABLE OF CONTENTS

FEEDBACK

### MORE INFORMATION

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<http://www.dpi.nsw.gov.au/agriculture/soils/salinity/salinity-and-crops/saline-irrigation>



There is evidence that cotton crops that follow maize crops have more vigour and higher yields than cotton-on-cotton rotations in adjacent paddocks. Maize in these areas can be planted as early as August and September and as late as January and even February. This flexibility makes it a very good option under irrigation conditions because it can be planted early and can use most of its water before the cotton plant utilises its major inputs.

Similarly, on a later plant, the maize is able to take advantage of any leftover water allocations and provide a profitable option.

In recent seasons, maize has become more popular for silage in the traditional dairy regions of Australia. Very few crops can provide the tonnes per hectare or tonnes per megalitre of maize. The crop is a particularly good fit in the dairy sector, with the high-energy, low-protein maize silage a perfect complement to the high-protein pasture and pasture silage produced on Australian farms. Maize is often referred to as a ‘recipe crop’ and it will consistently produce high-quality yields of silage or grain under good management. <sup>2</sup>

## 1.1 Paddock selection

### 1.1.1 Soil types

Maize grows well on a range of soils but is best on deep, well-drained, fertile soils that are slightly acid to neutral (pH<sub>Ca</sub> 5.5–7.0). <sup>3</sup> However, in much of the inland where large areas of maize are grown, soil pH is commonly up to 7.5 or even 8.0. In addition, maize is much more susceptible to saline soils than sorghum, wheat and barley. <sup>4</sup>

Maize does not grow well in saline soils. Yield reductions of 10% to ≥20% can be experienced if soil extracts contain 2.0–4.0 dS/m, respectively. Yield decline is likely if irrigation water has salinity of >1.5 dS/m. Seedling and flower growth is most sensitive to salinity. <sup>5</sup>

Maize, like sorghum, is extremely sensitive to germinating and establishing in saline soils, but tolerance improves dramatically in maize as it grows in biomass.

Maize does not grow well on poorly drained soils, so most irrigated crops are grown in a minimum tillage system on permanent raised beds. Farmers using minimum tillage together with permanent beds report improvement in soil structure as well as cost and time savings. <sup>6</sup>

Much inland maize in the northern grains region is grown on clay-based soil, which, generally, is good soil with high water-holding capacity but more prone to waterlogging with either excessive summer storms or over-irrigation early in the plant life. This same soil type is also prone to compaction because of its fine particle size and clay content.

Maize can handle a very wide range of soil types both light textured and heavy clays, even though clay soils with high bulk densities can inhibit root development and moisture extraction. This is similar for other crops but bulk density values of 1.4 and rising would limit maize yields unless adequate irrigation water was available to alleviate the soil constraint.

The maize plant is vulnerable to soil compaction and this has a detrimental effect on maize yield in some irrigation systems, particularly if farmers are forced to harvest under wet field conditions or where field preparation occurs after a wet winter. In

<sup>2</sup> The Cob, August 2011. Maize Association of Australia, [http://www.maizeaustralia.com.au/cob\\_files/autumncob2011.pdf](http://www.maizeaustralia.com.au/cob_files/autumncob2011.pdf)

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<sup>6</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>



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many cases, the compaction occurs in the bottom of the actual furrow from land preparation through to post-planting operations.

Soil compaction has multiple effects on the plant:

- It reduces water-holding capacity and therefore increases waterlogging (causing an anaerobic environment).
- It reduces the plant's ability to develop an efficient root system to scavenge moisture and nutrients from depth.
- Water scheduling will be shortened because of the plants inability to scavenge at depth even though the probe may indicate otherwise.
- It makes the plant more prone to root, stalk and grain diseases because of stress through inability to scavenge.<sup>7</sup> It can also create an uneven crop.

**1.2 Paddock rotation and history**

Legume rotations and long fallows increase the availability of soil nitrogen (N; nitrate), reducing the N fertiliser requirement. Indicative N requirements for maize target yields are shown in Table 1.<sup>8</sup>

**Table 1: Nitrogen rates (kg N/ha) for maize yield targets of 4–12 t/ha as influenced by crop rotation.**

Previous crop to maize	Yield target (t/ha)				
	Dryland	Irrigated			
	4	6	8	10	12
Sorghum, cotton, sunflower, maize	100	150	200	250	300
Soybean	–	–	180	230	280
Cowpea, mungbean	70	120	–	–	–
Long fallow wheat	80	120	160	210	260
Long fallow faba bean	30	80	140	190	240
Long fallow chickpea	50	100	–	–	–
Lucerne	0	0	–	–	–

Dryland maize N estimates are based on Liverpool Plains climate and soils with cultivations older than 25 years

Many Group A herbicides can persist in the soil and cause damage to monocot crops such as wheat, barley, cereals, sorghum and maize.<sup>9</sup> Many of the Group B herbicides have plant-back periods of 6–26 months that must be observed before planting maize. Plant-back requirements are summarised in the NSW DPI Management Guide *Weed control in summer crops*.<sup>10</sup>

**1.3 Maize in crop rotations**

Crop rotation plays an important role in spreading risks associated with seasons and markets. As our knowledge of the agronomic value of rotations increases (reducing disease severity, lowering the risks of herbicide resistance, controlling hard-to-kill weeds, maintaining arbuscular mycorrhizae levels, legumes for an alternative source of N), fixed cropping systems are being replaced by opportunity-based systems that include a broader selection of crops. As such, summer cropping is playing an

7 Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

8 N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

9 M Widderick, A van der Meulen, J Churchett, A McLean (2015) Weed issues and action items. GRDC Update Papers 31 July 2015, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Weed-issues-and-action-items>

10 J Fleming, T McNee, T Cook, B Manning (2012) Weed control in summer crops 2012–13. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/pests-weeds/weeds/publications/summer>



increasing role in today's farming systems. The mix of summer and winter cropping is recognised for improving cash flow and reducing the overhead costs for small to mid-size enterprises. By spreading the workload throughout the year, greater productivity is achieved from machinery and labour resources.

Excluding cotton and rice, sorghum accounts for 64% of the summer crop area sown in NSW. However, sunflower, maize, mungbean, soybean and safflower can add flexibility to the summer cropping program. Sunflower can be sown 4–6 weeks earlier than sorghum. As spring rainfall can be variable, an early sowing opportunity could mean the difference between sowing and not sowing a summer crop. Legumes fix their own N, and mungbean has a relatively short cropping period. Good seasons can be taken advantage of when a double-crop option such as mungbean can be included. Maize can be grown as an excellent source of silage as well as for grain, and there are hybrids with adaptation to locations across NSW. Maize and soybean have human consumption markets, providing an opportunity to diversify farm income.<sup>11</sup>

## IN FOCUS

### 1.3.1 In rotation with cotton

Rotation crops have been utilised by cotton producers in Australia since the early 1980s for perceived benefits to soil quality, cotton yield and profitability. The benefits of wheat and legume rotations on cotton crops have been well established. However, maize rotation is becoming more popular and it has gained recent interest with anecdotal field reports of increases in the following season's cotton yields of up to 25%.

Compared with continuous cotton cropping, a maize crop with more shoot and root biomass and a shallower root system may provide more organic matter to the soil and extract less water and nutrient from deeper soils, which would benefit the subsequent cotton crop. In order to test these ideas, water stress trials were established in the rainout shelters at the University of Queensland Gatton Campus.

University of Queensland researchers imposed water stress treatments at 38 and 71 days after sowing. Soil moisture content was monitored using a neutron moisture meter and crop root growth was investigated with soil cores taken consistently throughout the growing season until crop maturity. The results of the prolonged water stress trial showed that maize had higher root mass in upper soil layers, but extracted less water in 30–70 cm soil layers.

Maize with greater root mass in the upper profile resulted in increased macropores and consequently increased infiltration, which may lead to increased water availability to the following cotton crop.<sup>12</sup>

### MORE INFORMATION

[A Devereux \*et al.\* \(2008\) The effects of maize rotation on soil quality and nutrient availability in cotton based cropping. In 14th Australian Agronomy Conference.](#)

[Corn and cotton rotation. Du Pont Pioneer.](#)

Benefits and management suggestions include:

- early planting or late double-crop planting
- choice of quick to mid-season hybrids to suit your schedule
- changing your summer herbicide package to clean up difficult weeds
- rotating your cotton paddocks where disease is an issue

<sup>11</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries. <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

<sup>12</sup> A Devereux, S Fukai, NR Hulugalle (2008) The effects of maize rotation on soil quality and nutrient availability in cotton based cropping. In 14th Australian Agronomy Conference, [http://www.regional.org.au/au/asa/2008/concurrent/plant-nutrition/5815\\_devereuxaf.htm](http://www.regional.org.au/au/asa/2008/concurrent/plant-nutrition/5815_devereuxaf.htm)

## SECTION 1 MAIZE

TABLE OF CONTENTS

FEEDBACK

### MORE INFORMATION

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- harvesting early (or late) and getting your paddock back into production for the next crop
- higher yielding subsequent cotton crops.<sup>13</sup>

### 1.3.2 Pest and disease impacts

Management of diseases in maize must aim to reduce both the opportunity for disease infections and the likelihood that mycotoxins will be produced when infections occur. Strategies including crop rotation can be effective for preventative management of diseases such as rust.

Inoculum of diseases including turicum leaf blight or northern leaf blight (*Xerohilum turicum*) overwinters on stubble and maize volunteers and it should be accounted for in rotation plans. Inoculum is dispersed by wind and rain splash.

Crop rotation is also a key strategy in managing pests such as African black beetle (*Heteronychus arator*) in maize, including avoiding following recently cultivated pasture. In clay soils, sampling the seedbed prior to planting is difficult, but warranted if the risk is high. To estimate the soil population, dig and sieve soil from 10 randomly located quadrats (20 cm, 30 cm in depth). The only insecticide treatment available is an in-furrow application of chlorpyrifos during planting. However, this treatment is not effective when beetle numbers are high ( $\geq 10$  individuals/m) or when swarms of beetles fly into the crop after planting.

Because wireworms, including true wireworm (*Agrypnus variabilis*) and false wireworms (*Pterohelaeus darlingensis*, *P. alternatus*, *Gonocephalum macleayi*), have a wide host range, they can be present irrespective of crop rotation or weed control.<sup>14</sup>

### 1.4 Fallow weed control

Timely cultivation is a valuable method of killing weeds and preparing seedbeds. Most growers use combinations of mechanical and chemical weed control to manage their fallows or stubbles.

The basis of a successful dryland summer crop is a weed-free fallow. No-till and minimum-till fallows have become the norm; no-till has enabled crops to be sown at the optimum time and to be sown when it is too dry to sow into a cultivated fallow. In addition, no-till often reduces operating costs to less than those for cultivated fallows, with significant machinery and tractor-time savings.

Opportunity double-cropping following winter cereals has succeeded where there is sufficient soil moisture. In no-tillage systems, stubble retention is vital for improving soil structure, reducing soil erosion and degradation, storing soil moisture and providing a wetter seedbed. Farmers have moved away from cultivating fallows to minimum- and no-tillage by substituting knockdown and residual herbicides.<sup>15</sup>

Paddocks generally have multiple weed species present at the same time, making weed-control decisions more difficult and often involving a compromise after assessment of the prevalence of key weed species. Knowledge of your paddock and early control of weeds are important for good control of fallow weeds. Information is available for the most common problem weeds; however, for advice on individual paddocks you should contact your agronomist.

Benefits of fallow weed control are significant:

- Conservation of summer rain and fallow moisture (this can include moisture stored from last winter or the summer before in a long fallow) is integral to winter

<sup>13</sup> Corn and cotton rotation. Du Pont Pioneer, [http://www.pioneer.com/CMRoot/International/Australia\\_Intl/Publications/Cotton\\_Corn\\_Rotation.pdf](http://www.pioneer.com/CMRoot/International/Australia_Intl/Publications/Cotton_Corn_Rotation.pdf)

<sup>14</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

<sup>15</sup> J Fleming, T McNee, T Cook, B Manning (2012) Weed control in summer crops 2012–13. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/pests-weeds/weeds/publications/summer>

 **MORE INFORMATION**

<http://grdc.com.au/Resources/Factsheets/2014/08/Summer-fallow-spraying>

cropping in the northern region, particularly so as the climate moves towards summer-dominant rainfall.

- Modelling studies show that the highest return on investment in summer weed control is for lighter soils or in situations where soil water is present that would support continued weed growth.<sup>16</sup>

The Northern Grower Alliance (NGA) is trialing methods to control summer grasses. Key findings include:

1. Glyphosate-resistant and -tolerant weeds are a major threat to our reduced tillage cropping systems.
2. Although residual herbicides will limit recropping options and will not provide complete control, they are a key part of successful fallow management.
3. Double-knock herbicide strategies (sequential application of two different weed-control tactics) are useful tools but the herbicide choices and optimal timings will vary with weed species.
4. Other weed management tactics can be incorporated, such as crop competition, to assist herbicide control.
5. Cultivation may need to be considered as a salvage option to avoid seed bank salvage.

## 1.5 Seedbed requirements

Being large-seeded, maize does not need a very fine seedbed, although this is desirable, because large clods will reduce the effectiveness of pre-emergent residual herbicides. In coastal wet tropics, maize can be no-tilled into cane trash, avoiding cultivation prior to the wet season.

Row spacing needs to match the harvester front, and it may be necessary to remove compaction with a ripper where a maize row coincides with an old sugarcane inter-row.<sup>17</sup>

The uptake of no-tillage, tramlining and permanent beds (or bed renovation) has seen a reduction in the effect of compaction, particularly under dryland farming operations. If compaction is a known problem, deep ripping or subsoiling is recommended. Ripping the furrows will also enhance water infiltration with bed or furrow irrigation.

Improved soil structure and moisture conservation have also improved using minimum/no-tillage techniques.

Maize is prone to waterlogging; therefore, irrigation fields that have not been properly levelled will suffer unevenness across the field and a reduction in yield (Figure 1).

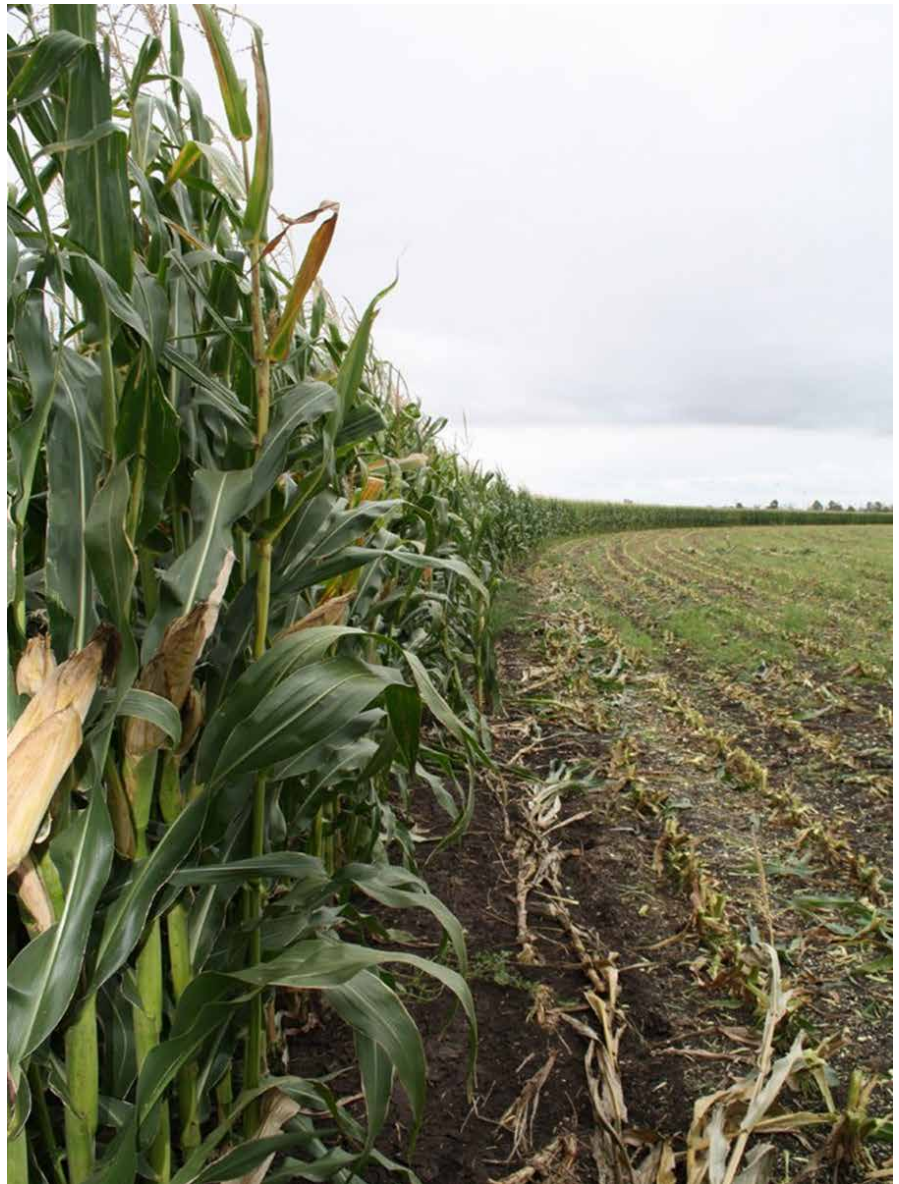
When planting dry and watering up, there is no need to plant deeper than 2–4 cm. The large seed of maize allows growers the flexibility to plant a little deeper if chasing moisture, as long as ground temperatures are adequate.<sup>18</sup>

<sup>16</sup> GRDC (2012) Make summer weed control a priority, Summer fallow management. Southern region. GRDC Fact Sheet January 2012, <https://grdc.com.au/?/media/8F16BE33A0DC4460B17317AA266F3FF4.pdf>

<sup>17</sup> QDAF (2010) Growing maize in the coastal Wet Tropics. Department of Agriculture, Fisheries and Forestry Queensland, [http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting/growing-maize-in-the-coastal-wet-tropics#Paddock\\_selection](http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting/growing-maize-in-the-coastal-wet-tropics#Paddock_selection)

<sup>18</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>





**Figure 1:** *Maize is prone to waterlogging so performs best on levelled fields.*

Photo: Pacific Seeds

**i MORE INFORMATION**

SoilWaterApp – [a new tool to measure and monitor soil water](#)

## 1.6 Soil moisture

### 1.6.1 Water requirements

Maize produces a large amount of dry matter and grain, but its yield is linearly related to ET and thus the moisture supplied. Maize requires 500–800 mm as the optimal range for yield, depending on climatic conditions<sup>19</sup>. Waterlogging can be as detrimental to maize yield as insufficient moisture. Although maize has a high water requirement, it can grow and yield with as little as 300 mm rainfall (40–60% yield decline compared with optimal conditions) depending on soil type and stored soil moisture. Crop failure would be expected if <300 mm of rain or irrigation were

<sup>19</sup> B Raymond, G Harris (2012) Irrigated corn—best practice guide. In Irrigated management of grain crops. WATERpak—a guide for irrigation management in cotton and grain farming systems, 3rd edition, [http://www.moreprofitperdrop.com.au/wp-content/uploads/2013/10/WATERpak-4\\_3-Irrigated-Corn-best-practice.pdf](http://www.moreprofitperdrop.com.au/wp-content/uploads/2013/10/WATERpak-4_3-Irrigated-Corn-best-practice.pdf)


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CJ Birch *et al.* (2003) *Agronomy of maize in Australia: in review and prospect*. In 5th Australian Maize Conference.

received in-crop.<sup>20</sup> However, crop success depends on soil type and starting soil moisture. Some of the best Vertosols can hold 250–300 mm of plant-available water for summer crops, so on these soils, 200 mm in-crop rainfall can still produce a viable yield.

## IN FOCUS

### 1.6.2 Crop water use

Maize originated in Mexico, and it is mainly grown in the warmer temperate regions and humid subtropics. It is a C<sub>4</sub> plant, which means that it has potentially more efficient use of CO<sub>2</sub>, solar radiation, water and N in photosynthesis than C<sub>3</sub> crops. Water Use Efficiency (WUE) of maize is approximately double that of C<sub>3</sub> crops grown at the same sites. Its transpiration ratio (molecules of water lost per molecule of CO<sub>2</sub> fixed) is 388, corresponding to 0.0026 in WUE (Jensen 1973), whereas that of wheat is 613 and soybean 704.

Although maize makes efficient use of water, it is considered more susceptible to water stress than other crops because of its unusual (monoecious) floral structure with separate male and female floral organs and the near-synchronous development of florets on a (usually) single ear borne on each stem.

Maize has different responses to water deficit according to development stage (Cakir 2004). Drought stress is particularly damaging to grain yield if it occurs early in the growing season (when plant stands are establishing), at flowering, or during mid–late grain filling (Heisey and Edmeades 1999). At the seedling stage, water stress is likely to damage secondary root development. During stem elongation (after floral initiation), leaves and stems grow rapidly, requiring adequate supplies of water to sustain rapid organ development; water-stressed plants are shorter and with reduced individual and cumulative leaf area (Muchow 1989). The most critical period for water stress in maize is 10–14 days before and after flowering, with grain yield reduced 2–3 times more when water deficit coincides with flowering than with other growing stages (Grant *et al.* 1989). During this period, ear growth is susceptible to competition from other organs that are still growing, as its growth is source limited, often leading to low grain number per ear and, occasionally, barren ears. Grain yield of maize suffering water stress at flowering and during grainfill is highly correlated with kernel number per plant (Bolanos and Edmeades 1996), indicating the importance of adequate water supplies during flowering.

The WUE of maize is a function of multiple factors, including physiological characteristics of maize, genotype, soil characteristics such as soil water-holding capacity, meteorological conditions and agronomic practices. To improve WUE, integrative measures should aim to optimise cultivar selection and agronomic practices.

<sup>20</sup> S Belfield, C Brown (2008) *Field crop manual: maize. A guide to upland production in Cambodia*. Cambodian Agricultural Research and Development Institute and NSW Department of Primary Industries, <http://aciar.gov.au/files/node/8919/maize%20manual%2072dpi.pdf>



### 1.6.3 Modification of agronomy to improve WUE

Drought resistance of a crop can be affected by many agronomic measures. Some measures are critical for improving WUE and can be achieved with relatively simple changes to production practices.

#### *Planting date*

Short crop duration contributes an important attribute of drought escape (Debaeke 2004); earlier maturing genotypes are better adapted to environments where the period of favourable water supply is short and the risk of water stress is relatively high. Planting date coupled with selection of appropriate genotypes facilitates drought escape by matching the crop growth cycle to rainfall and temperature patterns to minimise the chance of exposure to water deficit at drought-susceptible stages. Of course, selection of planting date and cultivar must be done to ensure that the thermal environment is favourable to crop establishment and completion of the life cycle. Where the length of the growing season is limited by the duration of the rainy season, the earliest possible planting of suitable cultivars reduces the probability of drought during the late grain-filling stage (Heisey and Edmeades 1999). A modeling approach to selection of planting date–cultivar combinations is included in Birch *et al.* (2006).

#### *Planting geometry*

Planting geometries or planting patterns can influence WUE, and there are many planting patterns for maize according to the environment and cultural conditions. The most common is an equal-row-spacing pattern of about 75–100 cm row spacing, with and different intra-row plant spacing producing different plant population densities. (Typically this is 25,000–33,000 plants/ha for dryland planting depending on cultivar and region, and 65,000–80,000 plants/ha under irrigation depending on cultivar, soil type and region.)

Intercropping may be used with maize; it has the benefit of using water from different soil layers by the companion crops and enhances overall WUE where water supply is adequate (Adiku *et al.* 1998). Skip-row sowing (with 1 row not planted between every 2 or 3 rows of sowing) has been proposed as a means of improving crop reliability by restricting water use early in the season and maintaining a reserve of water in the soil in the wide row space produced by the omitted row. Research has identified limited response in yield or WUE by using single-skip in maize, as has been confirmed in sorghum. There may be circumstances where wide rows are beneficial, but Australian research to date is unresponsive of the practice.

#### *Tillage*

Based on the level of organic residues on the soil surface, two broad classifications of tillage are used: conventional tillage and conservation tillage. Results of various investigations from almost all world climatic zones suggest that ploughing causes common soil-related problems of compaction, soil erosion, reduced water percolation and thus increased runoff and high energy and time requirements (Titi 2003). By contrast, conservation tillage, including no-tillage, ridge tillage, mulch tillage, and any systems with at least 30% residue cover remaining after planting (Derpsch 2001), is generally designed to reduce soil erosion (Reinbott *et al.* 2004); it also improves water infiltration (Guzha 2004) and water storage and thus yield potential and WUE (Hartkamp *et al.* 2004).

#### *Residue retention and plastic mulch*

In semi-arid areas, as much as 50% of total ET from a crop can be lost through evaporation from the soil surface (Unger and Stewart 1983). Mulching with crop residues is an obvious way to reduce evaporation, and

it may have other desirable effects such as reducing runoff, increasing infiltration, and decreasing surface temperature, contributing to improve WUE (Hartkamp *et al.* 2004).

Usually, surface mulching reduces evaporation by protecting the moist layer of air close to the surface from wind, and moderates soil temperature. Maximum soil temperature is often reduced because mulching materials generally reflect more solar radiation and have lower thermal conductivity than soil (Jalota and Prihar 1998). Retention of crop residue coupled with minimum tillage improves several measures of soil quality, sustains or improves crop production, and increases WUE of maize in semi-arid subtropical (Gicheru *et al.* 2004; Rahman *et al.* 2005) and humid tropical (Pramanik 1999) areas.

Plastic mulching is a well-established technique for increasing the profitability of many horticultural crops, and is being considered more widely for field crops. Large increases in yield have been achieved by using plastic mulching on rainfed maize, more than doubling yields (Fisher 1995). In cool climates that are marginal for crop establishment, plastic mulch may increase temperature while protecting water from evaporation. For cotton, use of integrated micro-topography and plastic mulch has increased WUE from 0.49 to 0.76–0.86 kg/m<sup>3</sup> (Jin *et al.* 1999), but adoption of this technology depends on cost-effectiveness and overcoming concerns about in-field degradation or removal and disposal of used plastic film.

#### *Weed control and fertiliser use*

Weeds compete with agricultural crops for light, nutrients and water (Norsworthy and Frederick 2005). The impact of weeds depends on the type and intensity of interference with crop plants, and in maize, like other crops, effective control of weeds leads to more efficient use of water (Peterson and Westfall 2004).

The most important management interaction in many drought-stressed maize environments is between soil fertility management and water supply. In areas subject to drought stress, many farmers are reluctant to risk economic loss by applying fertiliser, strengthening the link between drought and low soil fertility. Many review papers deal with the underlying physiology and individual nutrient effects on crop yield and thus WUE; reduced plant growth rate in nutrient-deficient plants is generally associated with reduced WUE (Bacon 2004).

Therefore, management of nutrient supply is a strategy to improve WUE. For example, Ogola *et al.* (2002) reported that the WUE of maize was increased by application of N, and Gao *et al.* (2004) found that silicon, although not widely considered a plant nutrient, improves WUE in maize plants under water stress by reducing leaf transpiration and water flow rate in xylem vessels.

#### *Irrigation management*

Although only about 18% of cropland is irrigated, it accounts for about 40% of world crop production (Gleick 2000) and two-thirds of total rice and wheat production (Rosengrant 2000).

The WUE can be improved with better systems for water conveyance, allocation and distribution (Hamdy *et al.* 2003), and water losses can be greatly reduced by using advanced irrigation methods, including drip irrigation systems that allow water to be delivered precisely when and where it is needed. Average application efficiencies of different systems are: surface (flood) irrigation 60–90%, sprinkler irrigation 65–90%, drip irrigation 75–90% (Fairweather *et al.* 2003). Distribution uniformity in the

## SECTION 1 MAIZE

TABLE OF CONTENTS

FEEDBACK

### MORE INFORMATION

R Huang *et al.* (2006) Water Use Efficiency in maize production—the challenge and improvement strategies. In 6th Triennial Conference, Maize Association of Australia.

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R Huang *et al.* (2006) The agricultural water supply challenge—the need for improved Water Use Efficiency. In 6th Triennial Conference, Maize Association of Australia.

### MORE INFORMATION

The impact of irrigation and nitrogen management on nitrogen uptake and yield in maize

field is also important for enhancing WUE and is favoured by precise delivery systems.

Management of maize irrigation at the field scale can be improved by quantifying the water balance and using advanced techniques for irrigation scheduling for more effective and economic use of limited water supplies. Irrigation scheduling is not necessarily based on full crop water requirement, but rather, designed to ensure the optimal use of allocated water. Deficit (or regulated deficit) irrigation is one strategy for maximizing WUE for higher yields per unit of irrigation water applied. The crop (e.g. maize crop) is exposed to a certain level of water stress either during a particular period or throughout the growing season, without significant reduction in yields (Sepaskhah and Ghahraman 2004). Success with deficit irrigation is more probable in finely textured soils such as Vertosols of the northern grain belt of Australia, by making water available at critical stages of maize development. Kang *et al.* (2000a) reported that soil drying at the seedling stage plus further mild soil drying at the stem-elongation stage is an optimum irrigation method for maize production in a semi-arid area. Alternate furrow irrigation (one of the two neighboring furrows is alternately irrigated during consecutive watering) and controlled alternate partial root-zone irrigation (part of the root system is exposed to drying soil while the remaining part is irrigated normally) are also ways to increase WUE of maize (Kang *et al.* 2000b; Kang and Zhang 2004).

Numerous strategies are available for improvement of WUE in maize. These include plant improvement strategies using conventional methodologies and biotechnology, and a range of agronomic practices. A combination of both will be needed to optimise maize production as water supplies become more limiting, with careful attention being given to the combination of practices that optimise WUE and crop reliability.<sup>21</sup>

### 1.6.4 Irrigation

Well-irrigated maize crops use water very efficiently, commonly yielding 16–18 kg grain/ha.mm water. Trial work has recorded efficiencies in excess of 20 kg grain/ha.mm water.

Irrigation WUE is affected by crop agronomy, irrigation system efficiency and seasonal conditions—primarily evaporation and in-crop rainfall. In generating yield response to applied water, it is as important to avoid waterlogging stress as it is to avoid stress from moisture deficits. Yields achieved in irrigated maize trials conducted by the NSW Department of Primary Industries are shown in Table 2.<sup>22</sup>

<sup>21</sup> R Huang *et al.* (2006) Water Use Efficiency in maize production—the challenge and improvement strategies. In 6th Triennial Conference, Maize Association of Australia, [http://www.maizeaustralia.com.au/events\\_files/Water%20use%20efficiency%20in%20maize%20-%20CJ%20Birch.pdf](http://www.maizeaustralia.com.au/events_files/Water%20use%20efficiency%20in%20maize%20-%20CJ%20Birch.pdf)

<sup>22</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

**i MORE INFORMATION**

[Irrigation cropping - can we afford the water?](#)

[Crop sequencing for irrigated double cropping within the Murrumbidgee Valley region](#)

**Table 2:** DPI irrigated maize hybrid evaluation trials.

Hybrid	Seed brand	No. of trials	Mean yield (t/ha)
32P55	Pioneer	1	10.61
Colossus	HSR Seeds	3	10.50
PAC 675	Pacific Seeds	3	10.49
31G66	Pioneer	2	10.45
3153	Pioneer	5	10.35
34N43	Pioneer	1	10.32
33V15	Pioneer	1	10.31
PAC 533	Pacific Seeds	1	10.30
Olympiad	HSR Seeds	3	10.30
PAC 424	Pacific Seeds	5	10.23
Hycorn 675IT	Pacific Seeds	3	10.23
33T39	Pioneer	1	10.17
Hannibal	HSR Seeds	4	10.16
31H50	Pioneer	4	9.94
XL80	Pacific Seeds	1	9.74
34B28IT	Pioneer	1	9.72
Victory	Nuseed	2	9.38
PAC 345	Pacific Seeds	5	9.32
Maximus	HSR Seeds	2	8.85
I.s.d. ( $P = 0.05$ )		1.12 t/ha	

Sites at Liverpool Plains 2002–2008

### Water budgeting

The amount of water required to produce high-yielding maize depends temperature and relative humidity during the growing season as well as other climatic factors affecting the rate of evaporation from the soil and transpiration from the plant. At Gunnedah, budgeting 3–6 ML of irrigation water applied to the field per ha will satisfy crop water requirements in 4 of 5 years. In the Murrumbidgee valley, irrigation water use ranges from 6 to 10 ML applied to the field. The average budget is 8–9 ML/ha.

A free-to-use online tool [CropWaterUse](#) can be used to model the crop water requirement for irrigated maize for locations in northern NSW and Queensland <sup>23</sup>.

Water budgeting is particularly important in the planning stages of maize production because maize is less tolerant of moisture stress than other summer crops. Irrigation strategies can be based on full or limited irrigation; however, ET is usually linearly related to the yield of the crop, and moisture stress at any stage of the crop development will reduce yield without the ability to compensate later.

### Types of irrigation

Maize is typically irrigated using furrow or flood irrigation. Sprinkler (lateral move and centre pivot) and drip irrigation methods are well suited to high-yielding maize production, partly because of the lower potential for waterlogging when using these methods. The higher system efficiencies of these methods, as shown in Table 3 below, are another significant advantage in maize production. <sup>24</sup>

<sup>23</sup> CropWaterUse. More Profit per Drop Irrigated Farming Systems, <http://www.moreprofitperdrop.com.au/irrigation-management/have-you-ever-wondered-how-much-water-a-crop-really-needs/>

<sup>24</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

## SECTION 1 MAIZE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

### MORE INFORMATION

[Increasing production with fast flow border check irrigation](#)

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**Table 3:** Indicative efficiency of irrigation methods.

Irrigation method	Indicative system efficiency
Flood or furrow	60–70%
Sprinkler—centre pivot, lateral move	85–90%
Drip	90–95%

### Peak water use

Daily water use for maize will vary through the season depending on the weather conditions and stage of growth. The crops ability to take up water increases with the development of the canopy. High water use occurs from tassel appearance through to early dent grain maturity. Approximately 70% of the crop's total water use will occur in this window 5–12 weeks after planting. During this time, cob initiation, flowering, pollination and kernel set occur.

Peak water use occurs during the 3 weeks following silking (weeks 10–12). The larger the canopy, the greater the water use during this period. Taller, denser crops will use more water because they intercept more light and they are exposed to more wind.<sup>25</sup>

### Scheduling irrigations

Irrigation frequency depends on the interaction between crop growth, stored soil moisture and climatic conditions—temperature, rainfall, wind and humidity. Moisture stress will occur before the crop has extracted all of the plant available water in the soil profile. Early in the season, when the root system is developing, it is recommended that irrigations are scheduled to occur when 40% of the available water is depleted.

Beyond tasselling the deficit can increase to 50%, except when conditions of extreme evaporative demand prevail. The deficit can increase to 75% when grain has reached early dent.

Using the recommended deficits, in the northern inland region of NSW the irrigation requirement for maize is similar to cotton, with 6–8 irrigations usually required. Crops in the southern NSW inland region are likely to require 10–12 irrigations through the season. During peak water use, the deficit will be reached every 7–10 days, depending on climate.

Daily water-use demands can be estimated where daily evaporation information is available. The daily water use of maize at key stages of growth, relative to both pan evaporation and the ET of a 'standard', crop are presented in Table 4. A large proportion of the soil water is taken up by the roots from within the top 30 cm of the profile. Monitoring soil moisture conditions at 25 cm is also a useful guide to moisture availability.<sup>26</sup>

**Table 4:** Daily water use of maize at key growth stages.

Maize growth stage	Daily crop water use relative to:	
	Pan evaporation	Evapotranspiration of a standard crop
5-leaf	25%	30%
Silking	95%	120%
Late grainfill	50%	60%

<sup>25</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

<sup>26</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>



Maize expresses the effects of moisture stress through an upward curling of the leaf margins. However, this is not a useful visual cue for scheduling irrigations. On hot summer days, the evaporative demand can be greater than maize's capacity to take in water. This leads to stress symptoms even when there is ample soil moisture.<sup>27</sup>

### Timing the first irrigation

Planting the crop into a full profile of soil moisture encourages rapid root growth and avoids waterlogging. This may require a pre-sowing irrigation. When starting with a full profile of moisture, maize should not require an irrigation before the V4 stage; however, the first in-crop irrigation should occur before any visible signs of moisture stress. There is a rapid increase in demand for nutrients during the period 5–8 weeks after emergence. The first irrigation should be timed to ensure that access to nutrients is not limited by water at this time, and it is critical that nutrient uptake not be interrupted by waterlogging.<sup>28</sup>

### Irrigation scheduling tools

As temperatures increase and the crop moves into rapid vegetative growth, the plant-available water capacity should be maintained between the refill point (50%) and full (100%). Prior to tasselling through to milk stage, the crop will require more frequent irrigations to maintain peak yield, particularly in hot, drier conditions and when the crops are taller with thicker canopies due to hybrid choice or agronomic management.

Irrigations should be scheduled based on the use of commercial in-crop monitors. Loggers that continuously monitor moisture at different depths throughout the profile (e.g. EnviroSCAN® and C-Probe®) allow accurate and continuous soil-moisture monitoring. This technology also allows users to access the information through wireless communication, so soil profiles can be measured from computers some distance away. Neutron probes also measure available soil water; however, logging is not continuous and only occurs as often as manually possible.

Other scheduling systems based on weather data such as WaterSched2, developed by Department of Agriculture, Fisheries and Forestry Queensland (QDAF), are also available. These tools utilise daily and seasonal weather to create and estimate crop ET so that, combined with on-farm data such as soil type and crop stage, irrigation requirements can be estimated.

### Impacts of stress

Moisture stress in the first 4 weeks of growth can reduce leaf expansion and crop height but is less detrimental to yield than later stresses. Stress at tassel initiation results in smaller cobs, and stress at tasselling (flowering) and silking (pollination) can result in unset kernels. Moisture stress following silking leads to reduced kernel size and increases the risk of mycotoxin contamination in the grain sample. Four consecutive days of moisture stress between tasselling and silking can reduce yield by 30%. Grain yield declines by 6–8% per day of moisture stress during the peak water-use period. After a period of moisture stress, the crop may take several days to recover regardless of soil moisture. If irrigation is applied after a period of stress, increase the flow rate to minimise the period of inundation. Prolonged saturation increases the risk of lodging if conditions become windy. Ideally, watering periods should not be more than 12 h.

Maize is not tolerant of waterlogging. Root activity is restricted because of lack of oxygen, and N losses through denitrification and leaching can be significant. There are two stages of growth when waterlogging is most damaging. The first is the seedling stage prior to the development of secondary roots. At this stage, crop water use is low, resulting in the soil drying slowly. Any marginal nutritional deficiencies are exacerbated, in particular zinc deficiency. Crop recovery is slow, and commonly,

27 N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

28 N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>





crops never ‘catch up’ from early waterlogging setbacks. The second is the period from tasselling to silking, when the crop is highly sensitive to both reduction in water uptake and interruption in the flow of nutrients. When furrow irrigating, an irrigation event is usually timed just prior to tasselling to allow time for the field to return to ideal conditions for this critical period.<sup>29</sup>

### Timing the last irrigation

Timing of the final irrigation needs to take into account the crop stage, soil type and plant-available water capacity. As grain maturity progresses, maize becomes less sensitive to moisture stress, allowing the last irrigation to be timed to dry down the soil profile in preparation for harvest. However, timing of the last irrigation will also depend on whether the crop is destined for a silage or grain market.

For grain crops, the last irrigation should be timed to ensure moisture is available until the grain is physiologically mature, as indicated by ‘black layer’ formation on grain (milk line score of 5). Maize generally reaches physiological maturity 2 weeks after the full dent stage, and the crop will usually require at least 60 mm of water to reach this. In heavier clay soils, the necessary moisture can be held in ~30 cm of moist soil and the final irrigation can be stopped up to 4–5 days after early dent. However, because of the limited moisture-holding capacity of sand-textured soils, irrigation may not be able to be stopped until a week after full dent.<sup>30</sup>

It is imperative to schedule the final irrigation based on knowledge of the water-holding capacity and actual depth and availability of moisture in the paddock, as provided by data loggers, to prevent wastage of water or yield truncation.<sup>31</sup>

Silage crops should be harvested 10–14 days earlier than grain crops, when the milk line score is 2.5. Because of the higher daily water use in early February, timing the last irrigation only a few days earlier at early denting (about 3 weeks after silking) will result in a deficit of ~90 mm by the time a 2.5 milk line score is reached.<sup>32</sup>

### Scheduling supplementary irrigation

If there is reduced irrigation water available or a forecast of insufficient rainfall, then yield targets for maize may need to be reduced and supplementary irrigation used rather than full irrigation. The yield of these crops is essentially water-limited but yield can be far higher than dryland alone if managed well. The alternative is to reduce the area cropped and use available water to fully irrigate. The choice between these two strategies will depend on individual farm gross margins, alternative rotation crops, paddock history and contracting arrangements.

In supplementary situations, the first irrigation should be timed prior to tasselling. Tasselling generally occurs 7–10 days prior to silking. When maize plants are moisture-stressed leading into tasselling, the development of silks lower on the plant may be slower than usual, which can result in pollen being shed and wasted before the silks emerge, leading to very poor kernel set. First irrigation just prior to tasselling (~8 weeks after planting) will usually offer the greatest return. If further irrigations are possible, they should be applied during the silking (R1) and blister (R2) stages. Preferably, irrigation should be continued until the end of the dough stage to prevent wilting, but because stress late in the season has the least impact of yield, irrigations from dent stage to maturity are not as critical. It should be remembered that high WUE is obtained only when crops are fully watered. Maize uses 250–300 mm of water before any yield is produced.<sup>33</sup>

### MORE INFORMATION

[Optimising maize yield under irrigation. GRDC Update Papers September 2008.](#)

[Crop guide, 2012 season. Du Pont Pioneer.](#)

[Growth potential. Corn growers’ workshop. Pioneer Hi-Bred Australia.](#)

[CJ Birch \*et al.\* \(2003\) Agronomy of maize in Australia: in review and prospect. In 5th Australian Maize Conference.](#)

29 N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

30 B Raymond, G Harris (2012) Irrigated corn—best practice guide. In Irrigated management of grain crops. WATERpak—a guide for irrigation management in cotton and grain farming systems, 3rd edition, [http://www.moreprofitperdrop.com.au/wp-content/uploads/2013/10/WATERpak-4\\_3-Irrigated-Corn-best-practice.pdf](http://www.moreprofitperdrop.com.au/wp-content/uploads/2013/10/WATERpak-4_3-Irrigated-Corn-best-practice.pdf)

31 B Raymond, G Harris (2012) Irrigated corn—best practice guide. In Irrigated management of grain crops. WATERpak—a guide for irrigation management in cotton and grain farming systems, 3rd edition, [http://www.moreprofitperdrop.com.au/wp-content/uploads/2013/10/WATERpak-4\\_3-Irrigated-Corn-best-practice.pdf](http://www.moreprofitperdrop.com.au/wp-content/uploads/2013/10/WATERpak-4_3-Irrigated-Corn-best-practice.pdf)

32 N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

33 N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

## IN FOCUS

### 1.6.5 Optimising maize yield under irrigation

Optimising maize yield under irrigation requires the correct combination of crop genetics, crop management and environmental factors. To produce maximum yield, crop ET requirements need to be met by a combination of stored soil water, in-crop rainfall and irrigation. Crop ET is the combination of water that goes through the plant (transpiration) and water that is lost from the soil surface (evaporation). Crop ET mainly depends on weather conditions, stage of crop growth, and available soil water. ET changes from season to season and from day to day.

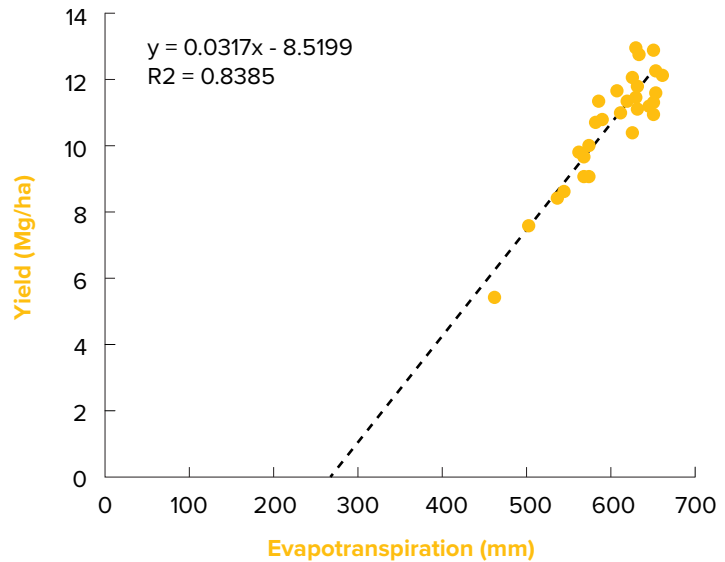
Crop genetics relates to choosing varieties that are adapted to local conditions and have adequate yield potential. Crop management relates to providing the crop with growing conditions that are as close as possible to optimal. This includes a variety of practices such as land preparation, sowing, soil nutrition, pest (insects, disease, and weeds) control and irrigation. These practices can significantly influence crop yield, either individually or in combination, and can generally be managed, depending on farmer's skills, knowledge and resources. Environmental factors, such as the weather, soil and water quality, cannot always be totally controlled.

Assuming that genetics, crop management, and environmental factors are properly managed, optimising maize yield under irrigation requires providing the crop with enough water to meet crop ET requirements at all times. Therefore, both correct amount and timing of water applications are critical. Considerable research has shown that maize yield is linearly related to crop ET; researchers have reported linear relationships between maize ET and yield. For example, Figure 2 shows the relationship adapted from two field experiments in Nebraska reported by Payero *et al.* (2008a, 2008b). At that location, ~270 mm of ET was required to start producing grain yield. This includes water needed just to produce vegetative growth and water that was lost by soil evaporation and did not contribute to grain yield. The slope of the line indicates that after the first yield unit was produced, each mm of ET produced an additional 0.0317 Mg/ha (= 31.7 kg/ha) of grain, and ~663 mm of ET was required to produce maximum yield. The results suggest that stress at any time during the growing period will reduce ET and, therefore, will reduce yield. The magnitude of the yield reduction depends on the severity, timing, and duration of water stress.

SECTION 1 MAIZE

TABLE OF CONTENTS

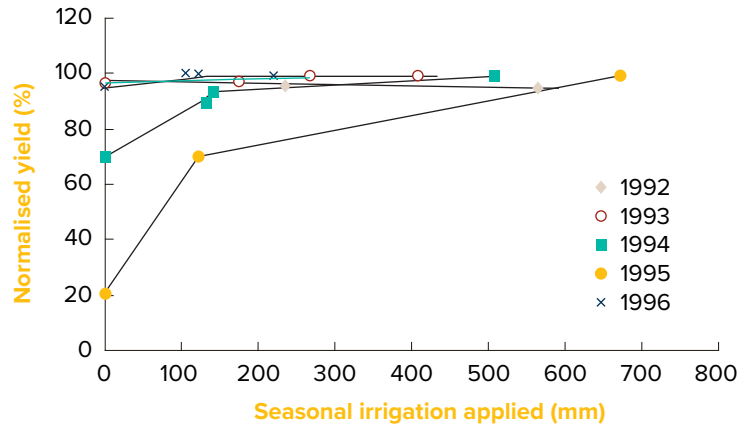
FEEDBACK



**Figure 2:** Relationship between maize yield and seasonal crop evapotranspiration obtained at Nebraska during 2005 and 2006.

Although the relationship between maize yield and ET is relatively consistent for a particular location, maize yield response to irrigation is very variable and changes with location and season, as shown in Figure 3, from a 5-year experiment conducted in Nebraska (Payero *et al.* 2006). In this experiment, four irrigation treatments were compared during 1992–96: no irrigation (Dryland), one irrigation prior to tassel formation (Early), one irrigation during the silk stage (Late), and irrigation following farmers’ practices (Farmer). The Farmer treatment was fully irrigated and always resulted in more irrigation.

In 3 of 5 years, there was no response to irrigation, because those were wet years. Nonetheless, the Farmer treatment still received ~500 mm of irrigation. During the two driest years (1994 and 1995), there was a response to irrigation. In 1994, the deficit-irrigation treatments received about 130 mm of irrigation and produced ~90% of normalised yield, whereas the Farmer treatment received 500 mm and produced only an additional 10% increase in yield. In 1995, the deficit-irrigation treatments received ~110 mm of irrigation and produced 70% of the normalised yield, whereas the Farmer treatment received 700 mm to get the additional 30% increase in yield. This illustrates that more irrigation does not always result in additional yield, and that sometimes, full yield can be obtained with no irrigation.

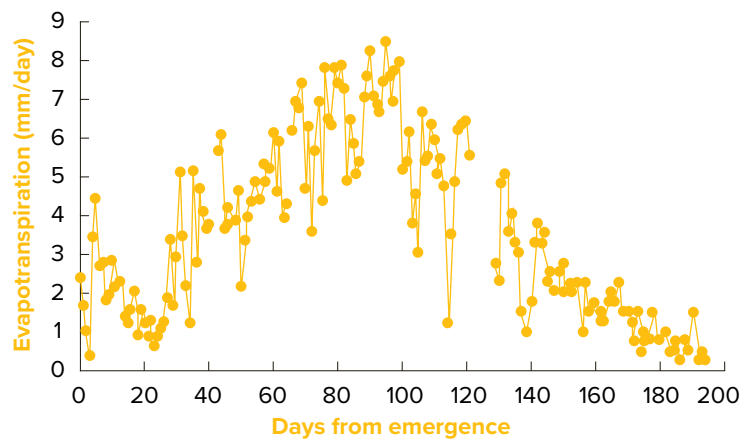


**Figure 3:** Relationship between seasonal irrigation and normalized yield for surface-irrigated maize in Nebraska.

Source: Payero et al. 2006

### 1.6.6 How much water is needed to optimise maize yield?

Crop ET depends mainly on weather conditions, crop cover (crop development stage and density), and available soil water, and therefore varies daily during the growing season and with location. For example, Figure 4 shows daily maize ET measured with an eddy covariance system in Nebraska (Payero et al. 2008c); maize ET increased from emergence, peaked at about 8.5 mm/day at about 90 days after emergence and then steadily decreased. The shape and magnitude of the ET curve will be different for each location and each season. Day-to-day variability in ET mainly reflects daily changes in weather conditions.



**Figure 4:** Crop evapotranspiration for maize measured at North Platte, Nebraska, during 2001, using an eddy covariance system

Source: Payero et al. 2008c

Daily values of maize ET (ET<sub>c</sub>, mm/day) for a given location can be estimated from weather data as:

#### **i** MORE INFORMATION

[Maize module. APSIM Initiative.](#)

[Multiple season maize simulations. APSIM Initiative.](#)

SECTION 1 MAIZE

TABLE OF CONTENTS

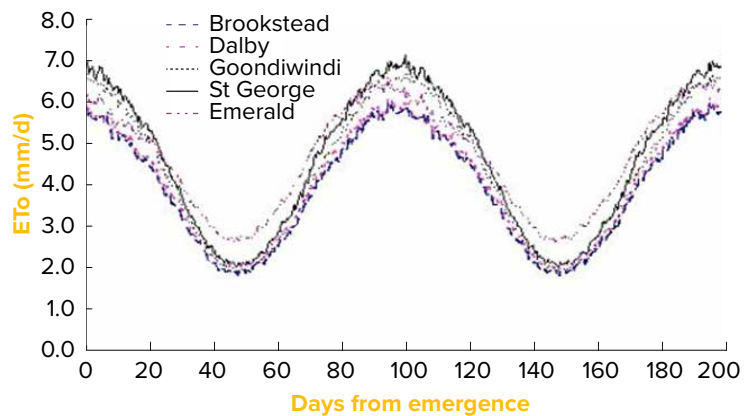
FEEDBACK

$$ET_c = ETo \times Kc \quad (1)$$

where ETo is grass reference evapotranspiration (mm/day), and Kc is crop coefficient. ETo can be calculated from weather data using a variety of methods. Locally tested Kc values for different crops are lacking in Australia, but values have been suggested from empirical studies around the world (Allen *et al.* 1998) that can be used to obtain a good estimation of ETc.

Figure 5 presents long-term average daily ETo values for different locations in Australia reported by SILQ, which were calculated from weather data. Figure 6 shows the crop coefficient (Kc) curve developed from international values suggested by Allen *et al.* (1998), and Figure 7 the average daily ETc for each location, calculated with Eqn 1 using the sowing dates shown in Table 5. Daily cumulative and seasonal ETc values are shown in Figures 8 and 9, respectively. Figures 7 and 8 show very similar daily and cumulative ET early in the season for all locations. However, considerable differences in ET begin to show at ~70 days after sowing. These graphs were generated to guide farmers as to the magnitude and timing of crop water use. As with any modelling approach, there are uncertainties, including:

- yearly and daily deviations in weather conditions from the long-term average
- variations in sowing dates
- differences among crop varieties, especially related to season length
- lack of locally determined Kc values
- uncertainties in ETo because SILO uses a fixed value for wind speed of 2 m/s.

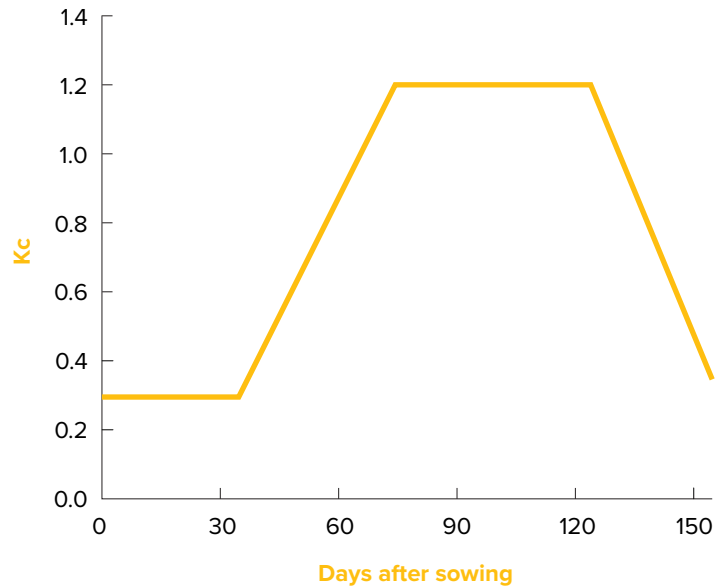


**Figure 5:** Grass reference evapotranspiration (ETo) for different locations in Australia.

SECTION 1 MAIZE

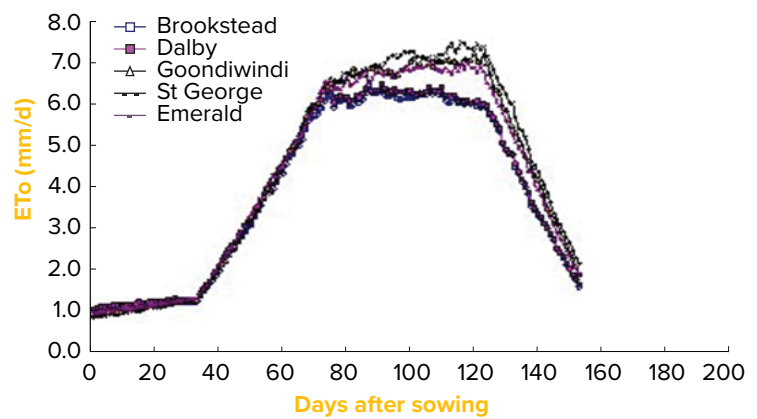
TABLE OF CONTENTS

FEEDBACK



**Figure 6:** Crop coefficient ( $K_c$ ) curve for maize

Source: Allen et al. 1998



**Figure 7:** Average daily maize evapotranspiration ( $ET_c$ ) calculated for different locations.

**Table 5:** Maize sowing dates for each location.

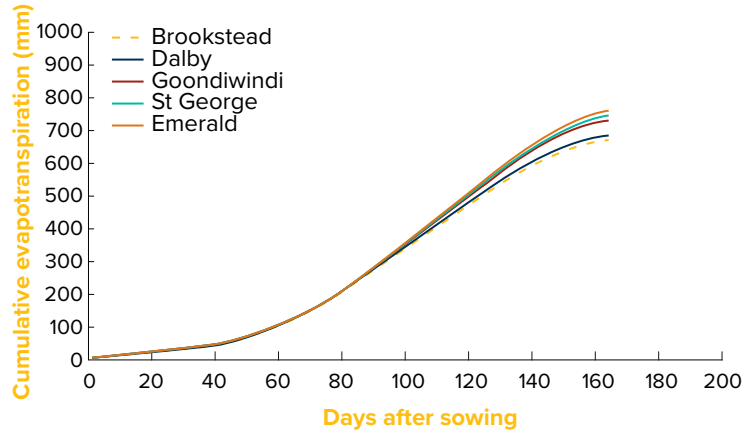
Location	Maize sowing date
Brookstead	15 Sept
Dalby	15 Sept
Goondiwindi	1 Sept
St George	20 Aug
Emerald	15 Aug



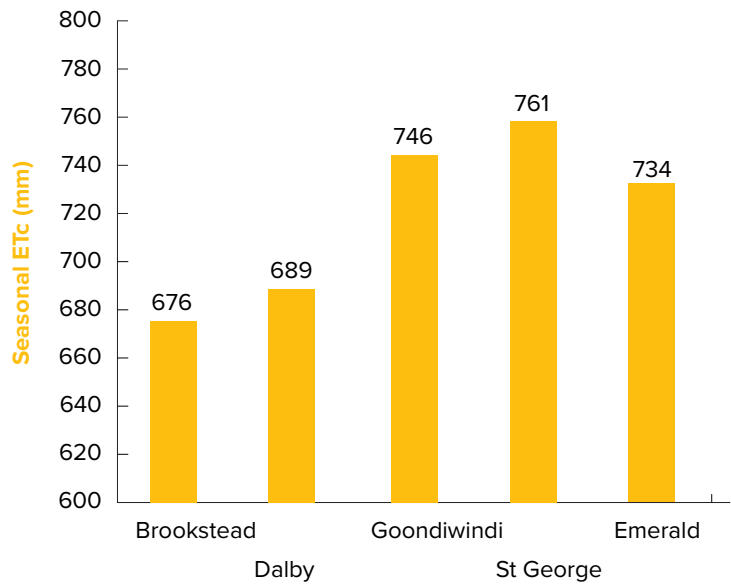
SECTION 1 MAIZE

TABLE OF CONTENTS

FEEDBACK



**Figure 8:** Average daily maize cumulative evapotranspiration (ETc) calculated for different locations.



**Figure 9:** Average seasonal maize evapotranspiration (ETc) calculated for different locations.

Figures 7–9 show that maize ET requirements to produce maximum yield can vary considerably with location, with a difference in seasonal ET of 85 mm between Brookstead and St. George. Applying more water than the ET requirements of the crop will not increase yields, and may reduce yields because of problems such as nitrate leaching and waterlogging. Irrigation is needed only to supplement ET requirements that cannot be met by water stored in the soil profile at sowing and by effective in-crop rainfall. It is therefore critical to have a means of measuring or estimating soil water content during the season to determine when irrigation is needed and how much (if any).

### 1.6.7 Some local data

To illustrate the irrigated maize yields that can be obtained locally and how much in-crop rain and irrigation water was required to obtain those yields, data were acquired from crop competitions conducted on the Darling Downs and the Lockyer Valley. The accuracy of the irrigation data from this dataset is variable and measured quantities were rarely provided. Estimates of applied irrigation water, when only number of irrigations was given, were based on the assumption that one flood irrigation was equal to 1 ML/ha. Data on stored soil water were seldom collected and are not included; however, stored soil water is an important source of water to meet crop water requirements and can be significant, especially in the heavy soils predominant on the Darling Downs.

Irrigated maize data from the crop competitions from 1987 to 2005 summarised in Table 6 show that maize yields averaged 11.5 t/ha during that period, but maximum yields ranged from 11.0 to 15.6 t/ha. Those yields were produced with seasonal irrigation depths ranging from 200 to 427 mm, with an average of 317 mm (100 mm = 1 ML/ha). In-crop rainfall ranged from 203 to 672 mm, with an average of 440 mm. Rain + irrigation ranged from 503 to 931 mm, with an average of 767 mm. Table 6 also shows the yield per unit irrigation and per unit of rain + irrigation. Although data in Table 6 do not tell us whether those yields could be obtained with less water (that would require more in-depth analyses), they provide an indication of actual values reported by real producers.<sup>34</sup>

**Table 6:** Irrigated maize data summary from crop competitions on the Darling Downs and the Lockyer Valley.

Year	Yield (t/ha)			Irrig (I) (mm)	Rain (R)	R + I	Yield/I (kg/ha.mm)	Yield/(R+I)
	Max.	Min.	Av.					
1987	11.1	8.3	9.6	344	452	796	28.0	12.1
1988	13.9	8.5	11.0	343	588	931	32.2	11.9
1989	11.0	8.5	10.0	300	203	503	33.4	19.9
1990	12.7	9.7	11.6	340	543	883	34.2	13.2
1991	11.7	8.3	10.2	427	360	787	23.8	12.9
1992	13.4	9.1	11.3	304	591	895	37.0	12.6
1993	13.5	7.5	10.7	300	248	548	35.7	19.6
1994	11.4	8.6	9.9	358	525	883	27.7	11.3
1995	12.0	8.7	10.4	340	386	726	30.5	14.3
1996	13.1	11.1	11.9	225	672	897	52.8	13.3
1997	14.4	11.1	12.5	283	261	544	44.2	23.0
1998	13.2	8.5	10.4	313	374	686	33.2	15.1
1999	14.3	11.8	12.8	375	517	892	34.2	14.4
2000	15.3	10.3	12.8	256			50.2	
2001	15.1	10.3	13.4	375			35.6	
2002	14.4	10.4	12.7	327			38.9	
2003	13.1	11.0	12.0	337			35.8	
2004	13.8	8.8	11.6	200			57.8	
2005	15.6	11.9	13.3	275			48.3	

<sup>34</sup> GRDC (2008) Optimising maize yield under irrigation. GRDC Update Papers September 2008. <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2008/09/OPTIMISING-MAIZE-YIELD-UNDER-IRRIGATION>

Year	Yield (t/ha)			Irrig (I) (mm)	Rain (R)	R + I	Yield/I		Yield/(R+I)	
	Max.	Min.	Av.				(kg/ha.mm)			
<b>Av.</b>	<b>13.3</b>	<b>9.6</b>	<b>11.5</b>	<b>317</b>	<b>440</b>	<b>767</b>	<b>37.6</b>	<b>14.9</b>		
<b>Min.</b>	<b>11.0</b>	<b>7.5</b>	<b>9.6</b>	<b>200</b>	<b>203</b>	<b>503</b>	<b>23.8</b>	<b>11.3</b>		
<b>Max.</b>	<b>15.6</b>	<b>11.9</b>	<b>13.4</b>	<b>427</b>	<b>672</b>	<b>931</b>	<b>57.8</b>	<b>23.0</b>		

### 1.6.8 Irrigation in Queensland

Maize requires 4–8 mL/ha of irrigation depending on location, seasonal rainfall and temperature conditions, and irrigation efficiency. Moisture use and availability should be monitored using soil-moisture monitoring tools. Consult local crop consultants and irrigation suppliers for the availability of such tools.

Ideally, dryland maize should be planted on a full profile of soil moisture. If moisture is marginal, consider planting sorghum instead.

For irrigated maize, the land should be pre-irrigated before the maize is planted.

Mild water deficits throughout the vegetative growth stages reduce leaf area. Severe moisture deficits reduce leaf number. Both reduce the plants' photosynthetic ability and affect grain yield. Because flowering is the critical stage for determining final crop yield, irrigated crops should be watered well during flowering and through to physiological maturity. It may be necessary to irrigate with flood irrigation every week in hot, dry weather, or more often with an overhead sprinkler system. Even if early soil moisture at planting has been adequate to produce maximum leaf area, moisture stress at later stages causes leaf senescence and, therefore, depression of yield.

Growers monitoring irrigation in maize crops should be aware that the effective rooting depth of maize is 100 cm.<sup>35</sup>

### 1.7 Yield and targets

Although maize is a summer crop, it is not heat loving like cotton (an arid plant). Maize is a subtropical plant rather than a temperate plant, and therefore prefers milder conditions with plenty of sunshine without excessive heat (Figure 10). As well as being temperature-sensitive, the maize plant is also sensitive to daylength.

Maize is a 'short day' plant; as the daylength (photoperiod) shortens, so does the time from germination to initiation of floral parts, although considerable variation for photoperiod sensitivity exists in the germplasm.

#### MORE INFORMATION

[N. Baxter \(2013\) Irrigated maize builds business resilience. GRDC Ground Cover Issue 106.](#)

<sup>35</sup> QDAF (2012) Nutrition, irrigation and weeds for maize. Department of Agriculture, Fisheries and Forestry Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/nutrition-irrigation>



**Figure 10:** *Maize prefers milder conditions with plenty of sunshine without excessive heat.*

Photo: Pioneer

Critical daylength appears to be 14.5–15 h. This means that maize grown between latitudes 23°S (~50 km north of the Tropic of Capricorn) and 23°N (roughly the Tropic of Cancer) does not experience days long enough to maximise yields.

As a result, the same hybrid planted south of the Tropic of Capricorn compared with planting in the tropical north will take longer to flower, will have more leaves and will be taller.

The best maize hybrids have a genetic yield potential of ~40 t/ha of grain. This potential varies according to climate, time of planting, plant populations, soil types and pH, water management, nutrition, weed control, presence of disease and other environmental factors.

The yield potential in Australia is ~20–22 t/ha because of the harsh climate. Excessive daytime temperatures of 40°C+ coupled with night-time temperatures of 28°–30°C for periods of up to 10 days during the crucial pollination–seedset period dramatically reduce yields. With this excessive heat, it also stretches resources trying to keep moisture up to the crops at such a critical time.

The stages of grainfill in maize are depicted in Figure 11:

1. Pollination. Stress will reduce the number of grains set but not grain quality.
2. Cell division. Stress will prevent proper cell division and can reduce grain size but not protein or starch components. Bushel weight can be affected in some genotypes.
3. Starch deposition. Stress will reduce starch deposition and can change the protein/starch ratio and seriously affect density and milling qualities.
4. Protein deposition. Stress at this stage has the greatest effect on grain density and millability. The storage proteins are laid down late in grainfill and they act as a ‘superglue’ to bind the starch granules into a very dense matrix. The role of N is critical in late grainfill to make or break ‘grits’ maize, of the right genotype: low N = low protein (<8.5 %) = starch type; high N = high protein (8.5–10 %) = grit type.

Sunlight provides the energy needed to produce starch. In association with good soil structure, which allows rapid early root growth, a deep and dense root system will

help ensure high yields. Root growth will be restricted in areas with dense subsoils, hardsetting topsoils, high water tables or salinity.

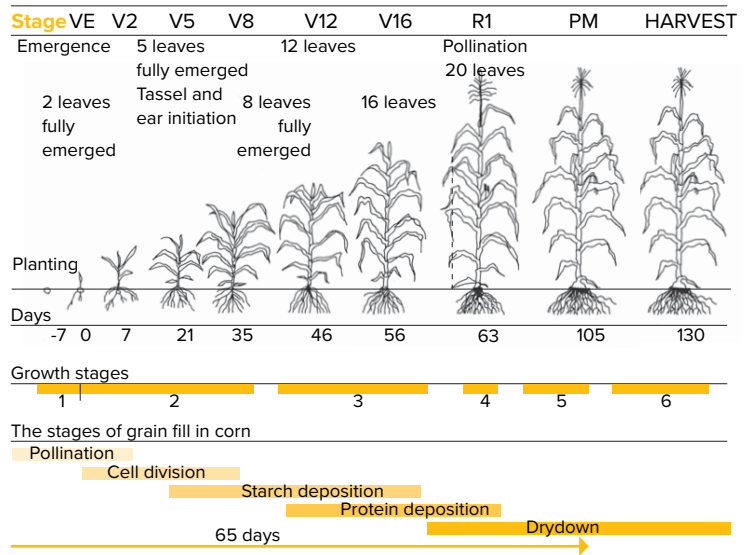


Figure 11: The stages of grainfill in maize.

Source: Pacific Seeds

**i MORE INFORMATION**

[Bureau of Meteorology. Sunshine: average daily sunshine hours.](#)

**i MORE INFORMATION**

[El Niño - Southern Oscillation.](#)

[Managing Climate Variability Climate Champion program.](#)

### 1.7.1 Seasonal outlook

Queensland Alliance for Agriculture & Food Innovation (QAAFI) produces regular, seasonal outlooks for summer crop producers. These high-value reports are written in an easy-to-read style and are free. For more information, visit [Seasonal Crop Outlook \(Sorghum\)](#).

For tips on understanding weather and climate drivers, including the Southern Oscillation Index (SOI), visit the [Climate Kelpie](#) website. Case studies of 37 farmers across Australia recruited as 'Climate Champions' as part of the Managing Climate Variability R&D Program can also be accessed at the website.

Australian CliMate is a suite of climate analysis tools delivered on the web, iPhone, iPad and iPod Touch devices. CliMate allows you to interrogate climate records to ask questions relating to rainfall, temperature, radiation, and derived variables such as heat sums, soil water and soil nitrate, and well as El Niño Southern Oscillation status. It is designed for decision makers such as farmers whose businesses rely on the weather.

Download from the Apple iTunes store at: <https://itunes.apple.com/au/app/australian-climate/id582572607?mt=8> or visit [Australian CliMate](#).

One of the CliMate tools, 'Season's progress?', uses long-term (1949 to present) weather records to assess progress of the current season (rainfall, temperature, heat sums and radiation) compared with the average and with all years. It explores the readily available weather data, compares the current season with the long-term average, and graphically presents the spread of experience from previous seasons.

Crop progress and expectations are influenced by rainfall, temperature and radiation since planting. *Season's progress?* provides an objective assessment based on long-term records:

- How is the crop developing compared to previous seasons, based on heat sum?
- Is there any reason why my crop is not doing as well as usual, because of below-average rainfall or radiation?



**i MORE INFORMATION**

[J Sabburg, G Allen \(2013\) Seasonal climate outlook improvements changes from historical to real time data. GRDC Update Papers.](#)

[Australian CliMate.](#)

- Based on the season's progress (and starting conditions from HowWet–N?), should I adjust inputs?

For inputs, *Season's progress?* asks for the weather variable to be explored (rainfall, average daily temperature, radiation, heat sum with base temperatures of 0, 5, 10, 15 and 20°C), a start month and a duration.

As outputs, text and two graphical presentations are used to show the current season in the context of the average and all years. Departures from the average are shown in a fire-risk chart as the departure from the average in units of standard deviation.<sup>36</sup>

The Bureau of Meteorology has moved from a statistics-based to a physics-based (dynamical) model for its seasonal climate outlooks. The new system has better overall skill, is reliable, allows for incremental improvements in skill over time, and provides a framework for new outlook services including multi-week/or monthly outlooks and the forecasting of additional climate variables.<sup>37</sup>

### 1.7.2 Water Use Efficiency

Maize is one of the highest yielding crops for both dry matter and grain production per hectare. Consequently, it has a high water requirement. It also is one of the most water-efficient crops because it produces a large amount of grain and dry matter per millimetre of water. However, it must have adequate water available to achieve this potential. At the same time, we should not underestimate the yield losses that can occur from too much water or waterlogging.

Most damage occurs in very young crops when they are developing their massive root system. Waterlogging is a result of badly drained soils or fields that are poorly developed, excessive rainfall or irrigation. Too much water in the root-zone can be as detrimental as not enough water being available to the plant.

Yield reductions of up to 50% can result if maize is wilted for 4 days at the end of the pollination period (Table 7). Even in the dough stage, 4 consecutive days of wilting can reduce yield by 40%. On the other hand, 4 days of wilting at least a week prior to tasselling caused only had a 10% reduction in yield.

Maize is moisture-stressed when the edge of the leaf starts to curl inwards. Under hot, low-humidity conditions, stress symptoms may occur despite adequate soil moisture and before the refill point (the point below which the crop may experience yield losses due to moisture stress) has been reached.

As with N and phosphorus (P), the maize plant uses the majority (70%) of its moisture requirement 3 weeks either side of tasselling.

Maize has a much longer grain-filling period than crops such as sorghum, roughly one-third longer, hence the importance of water management during this period (Figure 12).

A high-yielding maize crop will be very water-efficient; total Water Use Efficiency should be 22–30 kg/mm for well-managed crops. The total amount of water required will depend on the environment.

The main contributors to water use are wind speed, temperature and humidity. Water use can be manipulated in some locations through hybrid selection and planting rate.

Daily water use varies during the season depending on growth stage and weather conditions. The crop's ability to take up water increases as the canopy develops, peaking at the silking stage.

Weather conditions that are hot, dry and sunny will increase the crop's water requirement. Taller and denser crops will use more water than shorter crops because they intercept more sunlight and they are more exposed to wind. It is important to have knowledge of soil water depletion and the ability of your soil to hold water.

<sup>36</sup> Australian CliMate—Climate tools for decision makers, [www.australianclimate.net.au](http://www.australianclimate.net.au)

<sup>37</sup> J Sabburg, G Allen (2013) Seasonal climate outlook improvements changes from historical to real time data. GRDC Update Papers 18 July 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Seasonal-climate-outlook-improvements-changes-from-historical-to-real-time-data>

## SECTION 1 MAIZE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

**Table 7: Effects of moisture stress on maize a various stages.**

Early growth stage	Affects leaf cell enlargement resulting in smaller leaves, a shorter canopy and a reduction in potential yield.
Pollen shed	Severe moisture stress at pollination will give poor pollination and reduced kernel development. Yield losses at this stage can be as high as 5% per day.
Silking/fertilisation	During this 3-week period maximum water usage occurs and a stress during the early part of this period will affect kernel numbers. Stress during the latter part will affect kernel weight.
Grainfill	Stress at this point will hasten maturity, reducing photosynthesis and starch production. After a period of severe water stress, the maize plant may take several days to recover despite plentiful soil moisture.
Pre-physiological	The last watering is important for final kernel size and therefore weight; maturity especially for producers growing contracted grit maize.

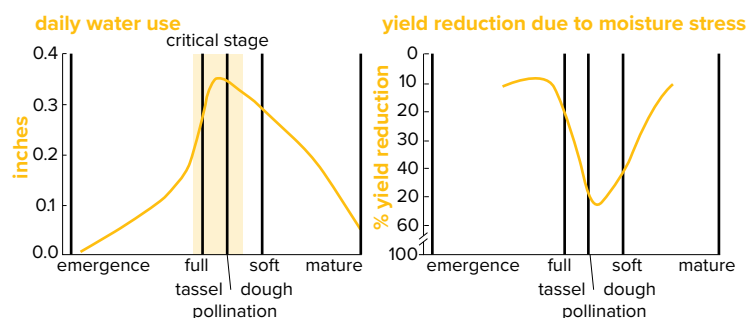
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CJ Birch *et al.* (2003) *Agronomy of maize in Australia: in review and prospect.* In 5th Australian Maize Conference.

[http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0003/175908/East-dryland-maize-12-13.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/175908/East-dryland-maize-12-13.pdf)

[https://dpiir.nt.gov.au/\\_data/assets/pdf\\_file/0016/233413/tb326.pdf](https://dpiir.nt.gov.au/_data/assets/pdf_file/0016/233413/tb326.pdf)

<https://publications.qld.gov.au/dataset/agbiz-tools-plants-field-crops-and-pastures>



**Figure 12: Moisture management in maize.**

A maize crop will extract only a portion of available water before moisture stress sets in. Often the soil profile may not be fully wet due to insufficient water applied, restricted infiltration or excessive runoff.

It is important to base irrigation periods or 'scheduling' on the allowable depletion or allowable water deficit at various stages of the season. This is often called the 'refill point'. Allowable depletion is the point below which the crop may experience yield losses due to moisture stress.

As roots are not fully developed prior to tasselling, it is suggested that depletion does not exceed 40%. During tasselling and grainfill, this figure can rise to 50% unless extreme temperatures prevail.

Depletion at maturity can be up to 75% under moderate conditions.

A rough guide is that an irrigated maize crop in southern NSW–Victoria will receive 10–12 waterings during its life (longer days, fewer cloudy days and water-holding capacity lower than in northern NSW).

During peak water use, watering may take place every 7–10 days, depending on temperatures. On the other hand, in northern NSW–Queensland, 5–7 waterings are usually required with scheduling every 10–14 days, again depending on temperatures.<sup>38</sup>

Budgets can be found through the state departments and can then be tailored for a farmer's own situation.

<sup>38</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

**i MORE INFORMATION**

[D Rodriguez et al. \(2013\) Relay-cropping extends cropping window. Ground Cover Issue 104.](#)

[Correct crop sequencing – Decision support tool](#)

[Water Use Efficiency. Crop yields and global food security. ACIAR.](#)

[Considerations for double-cropping corn following hay in Pennsylvania. Penn State.](#)

[Making corn after wheat work. The Farm Press 2009.](#)

[K Johnson. Under exploited double crop opportunities. Purdue University.](#)

### 1.7.3 Nitrogen-use efficiency

Because maize is a big producer of dry matter, it is also a big user of nutrients, which many Australian soils are not capable of supplying without the addition of fertilisers. Soils should be regularly tested so you are aware of the nutrient status (both macro- and micro-nutrients), pH and organic matter.

Once you have analysed soil test results, you can plan a fertiliser program based on available nutrients and most importantly your budget or expected yield. Remember, if growing maize for silage you will need a slightly different fertiliser program than what you would for grain.

The three primary nutrients required for a maize crop are N, P and potassium (K), which represent 83% of total nutrients.

The secondary nutrients sulfur, calcium and magnesium comprise another 16%, which means the micronutrients only represent 1% of the total nutrient uptake.

Maize takes up the large majority of its K by silking but requires a supply of N and P beyond grainfill. The accumulation of water, N, P and K is rapid in the early stages of growth beyond the 4–5-week period.<sup>39</sup>

### 1.7.4 Double-crop options

Northern grain growers thinking of double-cropping should be well prepared in spring and should address questions of soil nutrition, water availability and weed pressure.

Most important is crop selection and checking for any potential issues from residual herbicides that may have been used earlier in the season.

Grain growers will also need to consider which weeds are likely to be present over summer so they can choose a crop that will allow the correct herbicide-chemistry groups to be used as part of their herbicide rotations.

For example, mungbean growers can use Group A chemistry in-crop for grass weed control, whereas sorghum growers tackling the same grass weeds can use Group K residual herbicides.

This approach will allow growers to keep on top of weed pressures while minimising the risk of resistance developing in the weed population.

Spray rigs should be checked to make sure you are getting the greatest efficiency out of the herbicide applied. If the spray rig is not set up properly, there is a much smaller margin for error when spraying in spring and summer, compared with the more forgiving conditions in winter.

Growers must check the plant-available water storage capacity in their soils so they can choose a suitable crop type. This ensures that they make an informed decision on crop establishment, which is critical for growing dryland maize. Agronomists generally recommend a full profile of moisture before sowing dryland maize because there is a limited time to accumulate soil water in a double-crop period. In addition, limited N is mineralised in a double-crop period, so large inputs are required to grow maize crop. It is preferable to double-crop out of maize into a pulse crop.

Deep soil testing is also encouraged so that you can make appropriate decisions about the amounts and types of fertiliser to be applied. Applying N as close as possible to the time the plant needs it will also help maximise uptake and minimise wastage.

New trials co-funded by the GRDC are highlighting the importance of pre-season soil testing to quantify profile mineral N reserves. The research is being conducted by QAAFI Principal Research Fellow Dr Mike Bell, who is examining the effect of N

<sup>39</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

SECTION 1 MAIZE

TABLE OF CONTENTS

FEEDBACK

**i** MORE INFORMATION

[K Becker \(2014\) Plan now for summer double crop. GRDC Media Centre.](#)

[Short-term profits, long-term payback. Choosing rotation crops. GRDC Fact Sheet.](#)

[S Clarry \(2013\) Different paths to success for Queensland maize growers. Ground Cover Issue 102.](#)

[L Jenkins \(2012\) Summer crop options for the central west—mungbeans & soybeans. GRDC Update Papers.](#)

[Theme 4. Advancing profitable farming systems. GRDC Project Summaries.](#)

**i** MORE INFORMATION

[Crop sequencing for irrigated double cropping within the Murrumbidgee Valley region](#)

[Double-cropping to absorb seasonal shocks](#)



fertiliser application time—pre-planting, at planting and in crop/side dressing—and product type (urea alone or in varying formulations).

It is hoped that the data will enable growers to adjust their fertiliser N rates more accurately to fit their circumstances.<sup>40</sup>

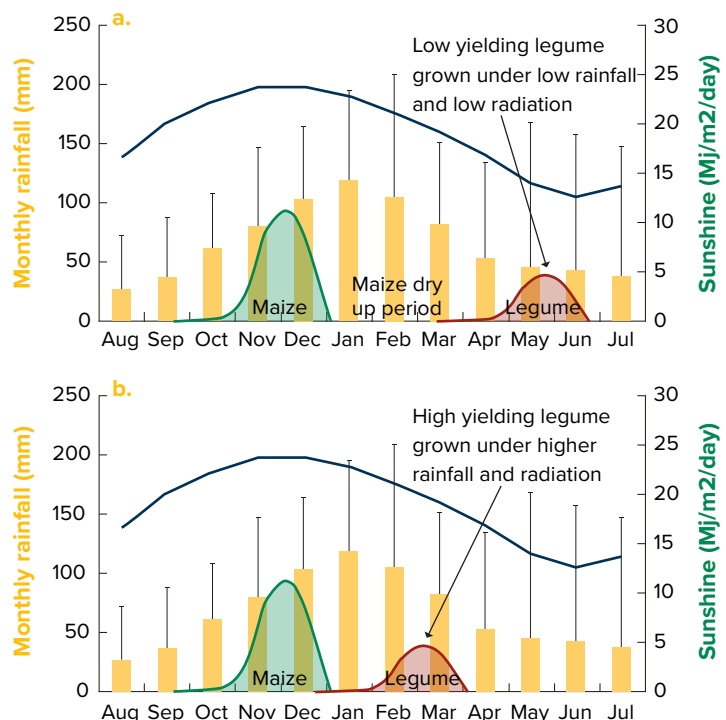
### 1.7.5 What is relay cropping?

Relay cropping means sowing a second crop into a standing crop before the first crop is harvested. This can be achieved quite accurately using controlled-traffic equipment.

For example, a medium-quick maturing maize crop (CRM 110) sown in September at Cecil Plains, Queensland, will mature by the end of December and be harvested 1–4 months later. This lengthy period impedes opportunities for double-cropping a summer legume in high-rainfall seasons (Figure 13a). However, if a mungbean crop is relay-planted into the maize at maturity there would be a 43% chance that the crop would receive >250 mm of rain between December and March (Figure 13b) and thereby yield an additional crop in nearly every second year.

Technologies to relay-sow a crop into an existing standing crop are available for wheat–mungbean and sorghum–chickpea combinations.

Researchers are investigating the required machinery innovations with the machinery industry to develop and adapt equipment for opportunistic relaying of maize–mungbean.<sup>41</sup>



**Figure 13:** Time course of rainfall and sunshine availability for crop growth and matching crop demand for resources in (a) single-cropping and (b) relay-cropping systems at Gatton, Queensland.

<sup>40</sup> K Becker (2014) Plan now for summer double crop. GRDC Media Centre October 2014, <http://www.grdc.com.au/media-centre/media-news/north/2014/10/plan-now-for-summer-double-crops>  
<sup>41</sup> D Rodriguez *et al.* (2013) Relay-cropping extends cropping window. Ground Cover Issue 104, May 2013. GRDC, <http://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-104-May-June-2013/Relay-cropping-extends-cropping-window>



## IN FOCUS

### 1.8 Relay cropping extends cropping window

#### Key points

- Opportunistic 'relay cropping' could be a new transformational practice able to squeeze two crops into a single season.
- Modern controlled-traffic and seed technologies facilitate the mechanised management of relay-crop arrangements.
- Trials in Queensland show significant production and financial gains from opportunistic cereal–legume relay cropping.

#### Could the relay-cropping systems from the Argentine Pampas open a new frontier for the northern grains industry?

It is becoming clear that the productivity gains required for Australian agriculture to remain competitive and contribute to the increasing global demand for food, fibre and energy will not only need small incremental gains in productivity, but may also require transformational changes to existing production systems (Figure 14).



**Figure 14:** *Twin-crop sowing: soybeans and sunflowers.*

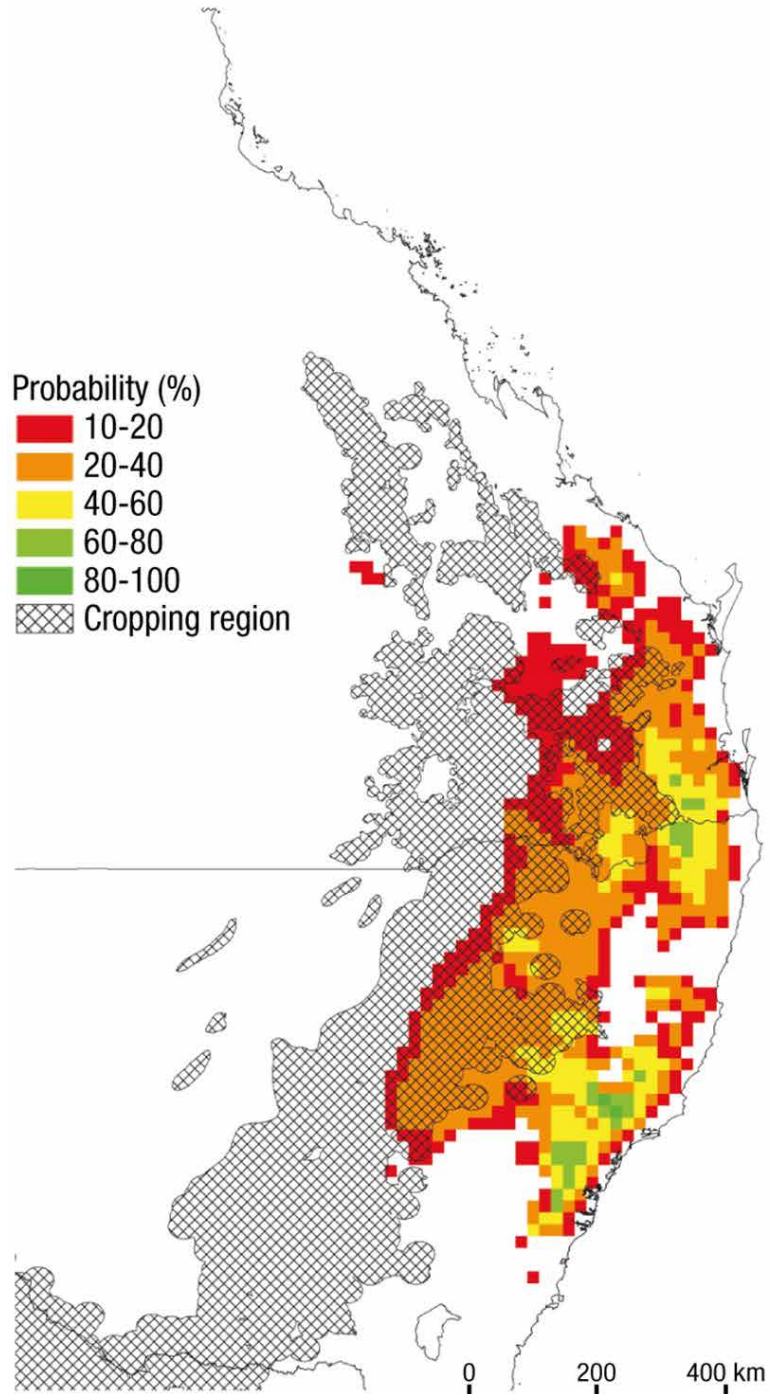
The challenge for growers and researchers is to devise new cropping systems or 'breakthrough innovations' that sustainably and substantially increase production with minimal risk.

Australia's northern grain-growing region has a predominantly summer-rainfall pattern that imposes constraints on existing cropping systems, but also provides opportunities to maximise the use of available resources such as rainfall, sunlight, temperature and soil nutrients.



### 1.8.1 Constraints

Constraints occur when production resources are concentrated into a few months of the year. The practice of growing a single crop per year per field wastes large proportions of key inputs such as rainfall and sunlight. For example, rainfall that occurs outside the crop growth period is highly susceptible to losses by deep drainage, run-off and evaporation.



**Figure 15:** Probability of finding the Parana (Argentine Pampas) climate in northern NSW and south-eastern Queensland cropping regions.

## 1.8.2 Opportunity

Opportunity arises when increasing the proportion of these resources that is used by crops and transformed into yield.

Scientists from the University of Queensland and QDAF, with the support of the Australian Centre for International Agricultural Research and the collaboration of SIMLESA partners (<http://aciarc.gov.au/simlesas>), are running trials at QDAF's Gatton Research Station that are already helping Queensland's Darling Downs growers.

As in commercial farms from the Argentine Pampas, growing multiple crops on the same area of land during the same season could help Queensland growers to reduce water 'leaks' and increase land productivity and gross margins. Figure 15 is a map of Queensland showing the areas with a similar climate to the Argentine Pampas.

Initial results show that relay-cropping mungbeans into a maize crop between maturity and harvest can more than double land productivity (2.4-fold increase) and increase gross margins 1.5-fold (Table 8). However, mungbeans sown outside this planting window produced low grain yields and returned a negative gross margin.

**Table 8:** Maize and mungbean yields from various cropping systems.

Cropping system	Grain yield (t/ha)		Gross margin (\$/ha)		
	Maize	Mungbean	Maize	Mungbean	Total
Sole maize	9.38	–	1808	–	1808
Mid-vegetable relay	9.44	0.02	1808	–399	1409
Mid-grainfill relay	9.56	1.24	1840	579	2419
Physiological maturity relay	NA	1.59	NA	858	2666
Double crop	9.38	0.37	1808	–119	1689

Maize and mungbean yields are moisture corrected to 14% and 12%, respectively. Gross margins are based on estimates from the NSW DPI Farm Budget Series Summer 2011–12. The maize component of the double-crop system is assumed the same as sole maize. NA, Not available

### MORE INFORMATION

[GM Murray, JP Brennan \(2009\) The current and potential costs from diseases of wheat in Australia.](#)

[K Owen, J Sheedy, N Seymour Root lesion nematode—Queensland. Fact Sheet.](#)

## 1.9 Nematode status of paddock

In the northern grain region, the root-lesion nematode (RLN) *Pratylenchus thornei* and the secondary species, *P. neglectus*, are found in three-quarters of fields tested.

Resistance and susceptibility of crops can differ for each RLN species. Maize is considered moderately resistant to both species.<sup>42</sup>

### 1.9.1 Nematode testing of soil

It is important to have paddocks diagnosed for plant parasitic nematodes so that optimal management strategies can be implemented. Testing your farm will tell you:

- if nematodes are present in your fields and at what density
- which species are present.

It is important to know which species are present because some crop-management options are species-specific. If a particular species is present in high numbers,

<sup>42</sup> K Owen, J Sheedy, N Seymour, Root lesion nematode—Queensland. Soil Quality Pty Ltd Fact Sheet, <http://www.soilquality.org.au/factsheets/root-lesion-nematode-in-queensland>

**i MORE INFORMATION**

<https://sites.google.com/site/crownanalyticalservices/>

[PreDicta B. SARDI Diagnostic Services.](#)

[Root-lesion nematodes. Management of root-lesion nematodes in the northern grain region](#)

**i MORE INFORMATION**

[Summer cropping options to manage root lesion nematodes](#)



immediate decisions must be made to avoid losses in the next crop to be grown. With low numbers, it is important to take decisions to safeguard future crops. Learning that a paddock is free of these nematodes is valuable information because steps may be taken to avoid future contamination of that field.<sup>43</sup>

Testing of soil samples taken either before a crop is sown or while the crop is in the ground provides valuable information.

### 1.9.2 Effects of cropping history on nematode status

Root-lesion nematode numbers build up steadily under susceptible crops and cause decreasing yields over several years. The amount of damage caused will depend on:

- the numbers of nematodes in the soil at sowing
- the tolerance of the variety of the crop being grown
- the environmental conditions, including rotations.

Generally, a population density of 2000 RLN/kg soil anywhere in the soil profile has the potential to reduce the grain yield of intolerant wheat varieties.

A tolerant crop yields well when high populations of RLN are present (the opposite is intolerance). A resistant crop does not allow RLN to reproduce and increase in number (the opposite is susceptibility).

Growing resistant crops is the main tool for managing nematodes. Information on the responses of crop varieties to RLN is regularly updated in grower and QDAF planting guides. Note that crops and varieties have different levels of tolerance and resistance to *P. thornei* and *P. neglectus*.

For more information, download [Management of root-lesion nematodes in the northern grain region](#).

Summer crops have an important role in management RLN. Research shows that when *P. thornei* is present in high numbers, two or more resistant crops in sequence are needed to reduce populations to low enough levels to avoid yield loss in the following intolerant, susceptible wheat crops.<sup>44</sup>

For more information on nematode management, see [GrowNotes Section 8: Nematodes](#).

### 1.10 Insect status of paddock

Emerging maize crops are prone to attacks from soil insects, and if left unchecked, a costly replant may be the only option, with no guarantee the same will not happen again. Seedling mortality of 30–40% will have a marked effect on yield due to the lower plant population.

Soil insects are more prevalent in early spring, coinciding with rising soil temperatures and pupae and larvae moving from deeper in the soil.

Changing farming practices, such as reduced tillage, no-tillage and permanent beds, may actually favour the build-up of some soil insects. Traditional forms of cultivation plus deep ripping seem to have an adverse effect on pupae and larvae and hence on soil insect populations.

The main soil insects to be controlled are wireworms, false wireworms, black field earwigs and African black beetle.

Still popular in Queensland, where it is registered, is the use of beetle bait, which is applied to the surface of the soil for the control of aboveground insects such as African black beetles, false wireworms, field crickets, wingless cockroaches and black field earwigs.

<sup>43</sup> QDAF (2009) Root-lesion nematodes—management of root-lesion nematodes in the northern grain region. Queensland Government, [http://www.daf.qld.gov.au/\\_data/assets/pdf\\_file/0010/58870/Root-Lesion-Nematode-Brochure.pdf](http://www.daf.qld.gov.au/_data/assets/pdf_file/0010/58870/Root-Lesion-Nematode-Brochure.pdf)

<sup>44</sup> K Owen, T Clewett, J Thompson (2013) Summer crop decisions and root lesion nematodes. GRDC Update Papers 16 July 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Summer-crop-decisions-and-root-lesion-nematodes>

From time to time grasshoppers, field crickets and wingless cockroaches can build up in numbers to become a problem. Control with a surface spray of a registered insecticide may be warranted.<sup>45</sup>

### 1.10.1 Soil sampling for insects

Crop rotation is also a key strategy in managing pests such as African black beetle in maize, including avoiding following recently cultivated pasture. In clay soils, sampling the seedbed prior to planting is difficult, but warranted if the risk is high. To estimate the soil population, dig and sieve soil from 10 randomly located quadrats (20 cm by 20 cm by 30 cm depth). The only insecticide treatment available is an in-furrow application of chlorpyrifos during planting. However, this treatment is not effective when beetle numbers are high ( $\geq 10$  individuals/m.) or when swarms of beetles fly into the crop after planting.<sup>46</sup>

It is particularly important to monitor and control soil-dwelling insects such as wireworms at sowing.<sup>47</sup>

Soil-dwelling insect pests can seriously reduce plant establishment and populations, and subsequent yield potential.

Soil insects include:

- [cockroaches](#)
- [crickets](#)
- [earwigs](#)
- [black scarab beetles](#)
- [cutworms](#)
- [false wireworm](#)
- [true wireworm](#)

Different soil insects occur under different cultivation systems, and farm management can directly influence the type and number of these pests:

- Weedy fallows and volunteer crops encourage soil insect build-up.
- Insect numbers decline from lack of food during a clean long fallow, but flare at sowing time when rain germinates weeds, attracting these soil insects.
- Summer cereals followed by volunteer winter crops promote the build-up of earwigs and crickets.
- High levels of stubble on the soil surface can promote some soil insects because of a food source; however, this can also mean that pests continue feeding on the stubble instead of on germinating crops.
- No-tillage encourages beneficial predatory insects and earthworms.
- Incorporating stubble promotes black field earwig populations.
- False wireworms are found under all intensities of cultivation but numbers decline if stubble levels are very low.

Soil-insect control measures are normally applied at sowing. Because different insects require different control measures, the species of soil insects must be identified before planting.

#### Soil sampling by spade

1. Take a number of spade samples from random locations across the field.
2. Check that all spade samples are deep enough to include the moist soil layer (this is essential).

<sup>45</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

<sup>46</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

<sup>47</sup> DPI (2005) Grain sorghum. Agfact P3.3.5. NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/146355/grain-sorghum.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/146355/grain-sorghum.pdf)

3. Hand-sort samples to determine type and number of soil insects.
4. Spade sampling is laborious, time-consuming and difficult in heavy clay or wet soils.

### Germinating-seed bait technique

Immediately following planting rain:

1. Soak insecticide-free crop seed in water for at least 2 h to initiate germination.
2. Bury a dessertspoon of the seed under 1 cm of soil at each corner of a 5 m by 5 m square at five widely spaced sites per 100 ha.
3. Mark the position of the seed baits, as large populations of soil insects can destroy the baits.
4. One day after seedling emergence, dig up the plants and count the insects.

Trials have shown no difference in the type of seed used for attracting soil-dwelling insects. However, use of the type of seed to be sown as a crop is likely to indicate the species of pests that could damage that crop.

The major disadvantage of the germinating-grain bait method is the delay between the seed placement and assessment.

### Detecting soil-dwelling insects

Soil insects are often difficult to detect because they hide under trash or in the soil. Immature insects such as false wireworm larvae are usually found at the moist-dry soil interface.

For current chemical control options see the websites of [Pest Genie Australia](#) or [APVMA](#).<sup>48</sup>

### MORE INFORMATION

[QDAF \(2011\) How to recognise and monitor soil insects.](#)

[Pest Genie.](#)

[APVMA.](#)

<sup>48</sup> QDAF (2011) How to recognise and monitor soil insects. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/recognising-and-monitoring-soil-insects>



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Release of a new generation of maize inbred lines 2013. The Cob, autumn 2014, p. 4.

# Pre-planting

## 2.1 Selecting maize varieties

Many maize varieties are available. The choice of variety will depend on market requirements, environmental conditions, whether the crop is irrigated, and the level of disease resistance required. Varieties are continually changing, so ensure that you have up-to-date varietal information.

Once the decision has been made to include maize in a summer cropping program, thought then must be given to which market you are aiming at and the group of varieties or the variety that best suits your situation (Table 1).<sup>1</sup>

**Table 1:** Key to maize ratings.

End use	Husk cover	Disease reaction	Stalk strength (lodging resistance)	CRM (days)
S, starch	TO, tight open	S, susceptible	* very poor	100–112 quick
P, processing	TC, tight closed	MS, moderately susceptible	** below average	113–115 medium quick
F, feed	MO, medium open	MR, moderately resistant	*** intermediate	116–120 medium
Sil, silage	MC, medium closed	R, resistant	**** above average	121–130 medium slow
	LO, loose open	NA, not available	***** very good	131+ slow
	LC, loose closed			

CRM, Cumulative relative maturity

<sup>1</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

## 2.2 Maize variety characteristics

Table 2: Maize hybrid characteristics.

Hybrid	CRM <sup>A</sup>	NSW area of adaptation	End use	Husk cover <sup>®</sup>	Disease reactions <sup>1</sup>		Lodging <sup>A</sup>		Company recommendations Target plant population/ha × 1000			Seed brand	
					Turcicum leaf blight	Rust	Cob rot	Root	Stalk	Irrigation	Dryland > 650 mm		Dryland < 650 mm
Titus	82	All	Feed; silage	M	8	7	9	9	9	75–100	40–75	35–45	HSR
Asterix	85	All	Feed; silage	M	7	7	9	8	9	75–100	40–75	35–45	HSR
P9400	94	Southern Inland	Feed; silage	M	7	6	6	7	7	80–100	–	–	Gentech Seeds <sup>^</sup>
P9911	99	Southern Inland	Feed; silage	M	5	–	5	5	5	80–100	–	–	Gentech Seeds <sup>^</sup>
P0021	100	Southern Inland	Feed; silage	M	7	6	tbc	7	7	75–95	–	–	Pioneer
PAC 301	102	Central/Southern NSW	Grain	VT	7	9	7	7	7	90–110	60–80	20–40	Pacific Seeds
Maximus	102	Quick	All	Feed; silage	M	8	9	7	9	75–100	40–75	35–45	HSR
Brutus	105		All	Feed; silage	MT	8	9	8	–	9	70–95	35–70*	20–35**
P1070	110	All	Feed; silage	M	6	5	7	8	9	70–90	45–65	20–35	Pioneer
Olympiad	112	All	Feed; silage	M	8	8	8	9	9	75–100	40–75	35–45	HSR
NeroIT	112	All	Feed; silage	M	7	8	7	9	9	75–100	40–75	35–45	HSR
HM-147	113	All	Feed; silage; potential processing	M	–	–	–	–	–	Suitable	Suitable	–	Heritage Seeds
HM-114	114	All	Feed; silage	T	5	7	–	8	9	60–75	30–45	20–30	Heritage Seeds
PAC 606IT	114	All	Grain; silage	–	8	8	8	–	–	–	–	–	Pacific Seeds
P1467	114	All	Feed; silage	MT	6	6	7	8	9	70–90	45–65	20–35	Gentech Seeds <sup>^</sup>
33V62	114	Medium – quick	All	White grain; silage; feed	M	5	–	9	–	70–90	45–65	20–35	Gentech Seeds <sup>^</sup>
P1545E	115		All	Waxy	M	7	4	6	8	8	70–90	45–65	20–35
PAC 624	117	All	Feed; silage	MT	7	7	7	8	7	65–75	35–45	20–35	Pacific Seeds

## SECTION 2 MAIZE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Hybrid	CRM <sup>Δ</sup>	NSW area of adaptation	End use	Husk cover <sup>∞</sup>	Disease reactions <sup>♠</sup>		Lodging <sup>^</sup>		Company recommendations Target plant population/ha × 1000			Seed brand	
					Turcicum leaf blight	Rust	Cob rot	Root	Stalk	Irrigation	Dryland > 650 mm		Dryland < 650 mm
P1756	117	All	Grit/ processing; silage; feed	MT	6	7	7	7	9	60–75	30–45	25–35	Gentech Seeds <sup>^</sup>
PAC 607IT <sup>°</sup>	118	All	Feed; silage	MT	7	7	7	8	7	65–75	35–45	20–35	Pacific Seeds
PAC 735	118	All	Grit; silage	MT	7	8	7	9	9	55–75	35–50	20–35	Pacific Seeds
Sirus	118	All	Feed; silage	M	8	8	7	9	9	75–100	40–75	25–35	HSR
Amadeus	118	All	Grit; silage; feed	M	9	9	8	8	8	75–100	40–75	35–45	HSR
Amadeus IT	118	All	Grit; silage; feed	M	9	9	8	8	8	75–100	40–75	35–45	HSR
P1813IT	118	All	Feed; silage	MT	7	7	7	7	9	60–75	30–45	25–35	Gentech Seeds <sup>^</sup>
P1888	118	All	Processing; silage; feed	T	7	6	8	7	7	60–75	30–45	25–35	Gentech Seeds <sup>^</sup>
HM-145	119	All	Feed; silage	–	–	–	–	–	9	Suitable	Suitable	–	Heritage seeds
PAC 345IT <sup>°</sup>	119	Medium Inland	Feed; grit; chips	MT	5	7	8	8	6	60–70	35–45	25–35	Pacific Seeds
PAC 727IT	123	–	Grits; grain; silage	–	8.5	8.5	8.5	–	–	–	–	–	Pacific Seeds
P2307	123	Medium-slow North Coast, South Central Inland	Feed; silage	VT	9	–	7	–	–	50–65	30–45	20–25	Gentech Seeds <sup>^</sup>
HM-102	123	Medium-slow Northern Inland; North Coast	Feed; silage	T	5	8	8	7	7	50–65	30–45	20–30	Heritage Seeds
GreenFeast <sup>®</sup>	Mixed	Quick All	Silage; grazing	M	8	8	8	–	8	80–100	45–80*	30–45**	HSR
<b>Speciality hybrids</b>													
Dolphin 12	105		Butterfly popcorn	MT	8	9	9	9	8	75–100	40–90	30–50	Dolphin Seeds
Dolphin 18	105		Butterfly popcorn	MT	8	8	9	8	8	75–100	40–90	30–50	Dolphin Seeds
Dolphin 37M	105		Mushroom popcorn	MT	8	8	8	9	9	75–100	40–90	30–50	Dolphin Seeds

<sup>°</sup> IT = imidazoline tolerant; # IR = imidazolinone resistant;  
<sup>∞</sup> Husk Cover; M = moderate; MT = moderate/tight; T = Tight; VT = Very Tight;  
<sup>^</sup> Lodging Resistance; 1 = Poor; 5 = Average; 9 = Excellent;  
<sup>♠</sup> Disease Reactions; 1 = Highly Susceptible; 5 = Intermediate; 9 = Highly Resistant; NR = Not Recommended;  
 – = No Information;  
<sup>Δ</sup> CRM = Corn Relative Maturity  
<sup>^</sup> formerly Pioneer  
 \* >600 mm  
 \*\* <600 mm

**i MORE INFORMATION**

[N Moore et al. \(2014\) Summer crop production guide 2014. NSW Department of Primary Industries.](#)

[Corn. Pacific Seeds.](#)

[Corn. Du Pont Pioneer.](#)

[Maize seed. HSR Seeds.](#)

[Summer crop planting guide. Northern edition. HSR Seeds.](#)

### 2.2.1 Maturity

In the maize belt of the USA, maturity is very important because of the relatively short growing season; a delay in planting of 3 or 4 days may mean changing to a different hybrid that has a slightly shorter cumulative relative maturity (CRM).



Due to video settings, this may not be viewable on mobile devices.

In Australia, the latitude of northern region production creates a wide planting window and maturity is not as critical.

Longer season varieties (111–130 days CRM) grown from the Liverpool Plains north have a higher yield potential than the quicker maturing varieties, but further south, the quicker varieties (108–111 days CRM) have similar yield potential. Yields for the range 100–111 days CRM have seen the largest improvements in the last 10 years.

Quicker maturity varieties than usual for a region may be planted in cases of:

- water cutbacks or wanting to finish the crop before the peak water requirements for other crops in the hot January–February period
- delayed spring planting with the aim of beating the summer heat before tasselling
- a late plant and a threat of an early frost interfering.<sup>2</sup>

### 2.2.2 Time to flowering

Under conditions of adequate soil moisture, mid- to slow-maturing hybrids will produce a higher yield than quick-maturing hybrids. Therefore, growers aiming for maximum yields should consider a mid- to full-season maturity hybrid. However, where irrigation is limited, a mid-season hybrid may produce greater yield per megalitre of water. This may also be the case in fully irrigated situations where it is desired to limit the number of irrigations for economic reasons or to plant a following crop to obtain maximum use of seasonal conditions. In dryland environments, commercial full-season hybrids can handle heat and moisture stress and then respond to a break in the weather.

Growers, particularly in dryland situations, may wish to reduce the risk of yield loss caused by unfavourable seasonal conditions by planting a number of hybrids, perhaps with a range of maturities.<sup>3</sup>

<sup>2</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

<sup>3</sup> QDAF (2012) Varieties and planting of maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting>

### 2.2.3 Adaptability

A variety does not perform equally under all conditions. The best varieties should yield and stand well in both favourable and less favourable conditions. Choose varieties that perform consistently under the chosen growing conditions.<sup>4</sup>

### 2.2.4 Cob height

Cob height tends to be correlated with maturity. Longer season hybrids usually have higher set cobs than quicker maturing hybrids. Excessive cob height, >1.5 m, can be a contributing factor to root lodging (especially if there is wind and rain around flowering) and to stalk lodging (particularly if stalk rot has infected the plants). Lodged plants can be slow to harvest and can reduce yield.<sup>5</sup>

Some hybrids, particularly three-way crosses, in very good conditions can produce multiple cobs, but they are usually expressed at lower plant populations. Year-in, year-out, a variety with one good cob that flexes its length rather than the number of cobs is more desirable.

Varieties with a longer shank, allowing cobs to hang down approaching maturity, have less cob damage than varieties with upright cobs at maturity.<sup>6</sup>

### 2.2.5 Husk cover

Husks function to prevent damage from *Helicoverpa* spp. larvae, reduce ear or kernel rots (caused by *Diplodia*, *Fusarium*) and smuts, and protect the grain from weathering. Therefore, a good husk cover (including tip cover) can be important if insects, disease, and pre-harvest rain are likely to pose threats. However, in areas where quick dry-down is necessary because of a short season, hybrids with light, loose husks may be best suited.<sup>7</sup>

Husk cover is an important consideration for coastal environments where protection from the weather is crucial. Open husk varieties grown in coastal areas tend to have more cob rots than tighter husk varieties. Tighter husk cover on processing hybrids is also more desirable, reducing infield stress fracturing.

On the other hand, a loose husk cover is often considered an advantage for inland growers because it encourages rapid dry-down. Recent findings indicate a higher level of mycotoxins in loose husk cover varieties than tighter husk cover varieties.<sup>8</sup>

### 2.2.6 Standability

Standability (resistance to lodging) is important because it reduces harvest losses and grain damage. Many factors contribute to standability, including resistance to stalk rots, good mechanical stalk strength, sowing rate and cob height. Most modern hybrids have good standability, but some seasonal conditions (e.g. water stress during grainfill) can cause serious lodging. Always choose hybrids with good to excellent standability and discuss optimal sowing population with your agronomist.<sup>9</sup>

4 Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

5 QDAF (2012) Varieties and planting of maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting>

6 Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

7 QDAF (2012) Varieties and planting of maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting>

8 Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

9 QDAF (2012) Varieties and planting of maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting>



 **MORE INFORMATION**

[CJ Birch \*et al.\* \(2006\) Analysis of high yielding maize production—a study based on a commercial crop. In 6th Triennial Conference, Maize Association of Australia.](#)

## 2.2.7 End use

Hybrids generally have specific grain characteristics, which govern their suitability for particular end uses such as milling for grits, stockfeed, silage or other special-purpose uses.<sup>10</sup>

## 2.2.8 Isolation

All white, waxy and popcorn varieties of maize must be grown in isolation (both in distance and time) from other maize varieties, as pollen from other crops will affect the quality of grain produced by these types. Seed companies or grain purchasers may have specific recommendations to follow.<sup>11</sup>

## 2.2.9 Tillers

Suckers (or tillering) are considered undesirable and untidy. Plant breeders try to eliminate this trait in their breeding programs even though it is very seasonal.

Some varieties are more prone to tillering than others. Tillering is usually triggered by high levels of nutrition, especially nitrogen availability to the plant early in its life, adequate moisture availability, cooler temperatures early in the crop's growth and lower plant populations.

Sometimes these tillers may have hermaphrodite ears on top of the tiller, but usually by harvest time, birds have raided the grain that has set. Research has shown no yield penalty with tillers. However, farmers often believe that the plant uses moisture and nutrients to grow tillers and, in some cases, a little grain on top. Later in the season, the main plant draws the nutrients back as the tillers tend to die off.<sup>12</sup>

## 2.2.10 Multi cobbing hybrids

Increases in maize yield are the result of improvements in breeding (G), agronomy (M), the farming system, and their interactions. For example, over the last 70 years in the USA, the interaction between crop improvement and management, such as increased plant population, have doubled maize yields from under 6 t/ha to just below 12 t/ha (Figure 1a). These results contrast with those in Australia, particularly for the Northern Grains Region where maize is mostly grown under rainfed conditions at very low plant populations (Figure 1b).

<sup>10</sup> QDAF (2012) Varieties and planting of maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting>

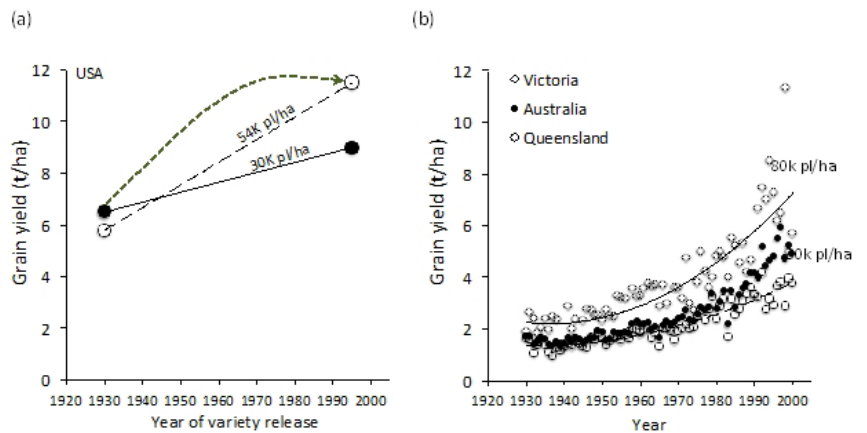
<sup>11</sup> QDAF (2012) Varieties and planting of maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting>

<sup>12</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

SECTION 2 MAIZE

TABLE OF CONTENTS

FEEDBACK



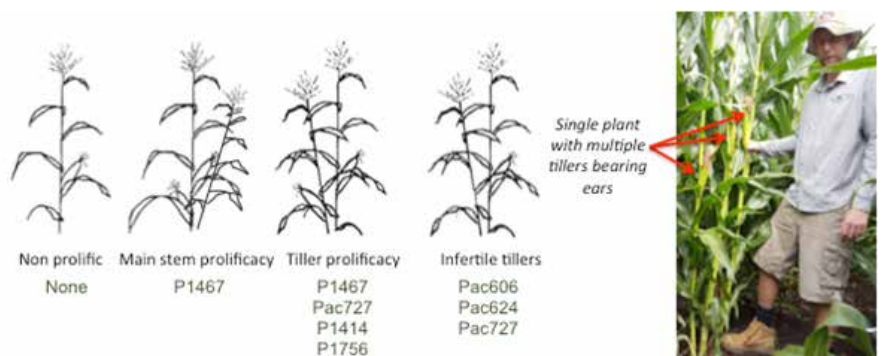
**Figure 1:** (a) Maize yield for old and new hybrids sown at old (30k pl/ha) and modern (54k pl/ha) plant populations in the USA (Adapted from Fischer, 2014). The dotted green line shows the combined benefit (interaction) from using new hybrids sown at higher densities. (b) Time series of maize yields for Victoria – mostly irrigated (open diamonds), Australian average (filled circles), and Queensland – mostly rainfed (open circles).

Source: ABS, 2015

In the Northern Grains Region, the uncertainty of rainfall around flowering, heat stress and high seed costs, force rainfed (but also irrigation) farmers to sow maize at low plant populations (20–40,000 plants/ha), missing out on G×M interactions observed in in the USA using modern hybrids.

Multi cobbing or prolific maize hybrids i.e. hybrids that develop a second or longer cob in the better seasons, have been proposed to compensate yield when sown at low plant populations.

Australian commercial hybrids show different types of yield formation characteristics, for example the capacity of plants to increase kernel numbers in good environments or seasons is called prolificacy (Figure 2). Multi cobbing hybrids are one of these types. Researchers have found that very few hybrids will develop a secondary cob on the main stem ('main stem prolificacy'); while most hybrids will produce tillers (suckers), some of which may develop fertile cobs ('tiller prolificacy'). Farmers consider tillering an undesirable trait, though under some circumstances tiller prolificacy can contribute up to 48% of the final grain yield (Table 3).<sup>13</sup>



**Figure 2:** Conceptual representation of most common hybrid types available in the Northern Grains Region. Hybrid x Management x Environment interaction may change hybrid's expression of the prolificacy trait.

<sup>13</sup> D Rodriguez, J Eyre, J McLean (2017) Managing climate risk in rainfed maize with multi cobbing hybrids. GRDC Update Papers 7 March 2017, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2017/03/Managing-climate-risk-in-rainfed-maize-with-multi-cobbing-hybrids>

**Table 3:** Characteristics of some commercially available maize hybrids in terms of prolificacy, defined as the capacity of some hybrids to increase kernel number under good conditions. Main stem and tiller prolificacy refers to hybrids that produce multiple cobs on the main stem, or on multiple stems, respectively. Primary cob flex refers to the maximum kernel number on the main stem cob. All hybrids will produce tillers.

Hybrid	Main stem prolificacy (Potential contribution to yield %)	Tiller prolificacy (Potential contribution to yield %)	Infertile tillers	Primary cob flex (Maximum primary cob kernel number)
P1070	31	18	Yes	1016
P1467	29	48	Yes	975
PAC606	6	5	Yes	1022
PAC727	4	37	Yes	674
PAC624	3	2	Yes	769

**Key points**

- Prolific multi cobbing hybrids planted at low plant population 2–3 plants/m<sup>2</sup> can compensate yield during good seasons and save on seed costs.
- There are important differences between hybrids, environments and managements on the expression and benefit of the multi cobbing trait.
- In early plantings, or when planted in cooler environments at low plant densities tiller cobs can contribute up to 48% of the total grain yield. In warmer environments (Central Queensland) tillers are less likely to develop a grain-bearing cob, and are considered to be a waste of resources.
- Even though tiller cobs may contribute to yield, they are half as efficient as main stem cobs at producing grain, and should be considered an undesirable trait by seed companies.
- Given the diversity of maize growing environments, there is need for eco-physiology work to develop better-adapted maize plant ideotypes in close collaboration with seed companies.<sup>14</sup>

**2.2.11 The final decision—which variety?**

As with many of crops, it is advisable to spread your maize production risks by planting a number of varieties or a true dual-purpose variety to provide options of selling your crop into many different markets.

Again, it is important to understand that the best yielding variety from last season is not necessarily the best selection. Consideration needs to be given to varieties that have performed over a number of years in good and bad seasons. Look for trial data in your local area, if not from your own property, or consult your agronomist.<sup>15</sup>

**2.3 Planting seed quality**

Growers expect high-quality, genetically pure seed. As a result, seed companies maintain quality control programs that monitor seed from harvest to purchase. ‘Traditional’ seed-quality tests, including mechanical tests and tests of genetic purity, seed germination and vigour, and seed health tests are used, and seed quality assessment techniques continue to evolve. Advances in molecular genetics are

<sup>14</sup> D Rodriguez, J Eyre, J McLean (2017) Managing climate risk in rainfed maize with multi cobbing hybrids. GRDC Update Papers 7 March 2017, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2017/03/Managing-climate-risk-in-rainfed-maize-with-multi-cobbing-hybrids>

<sup>15</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

**i MORE INFORMATION**

JM Peterson *et al.* (1995) Influence of kernel position, mechanical damage and controlled deterioration on estimates of hybrid maize seed quality. *Seed Science and Technology* Vol. 23.

EY Hosang *et al.* (2012) An alternative storage technique for maintaining seed quality in East Timor. In 16th Australian Agronomy Conference.

**i MORE INFORMATION**

AM Smith (1970) Effect of fungicides on the germination of maize seed after storage. *Australian Journal of Experimental Agriculture* Vol. 10.



allowing the release of new varieties differing essentially in one gene. New molecular biology approaches offer the potential to identify these subtle genetic differences.

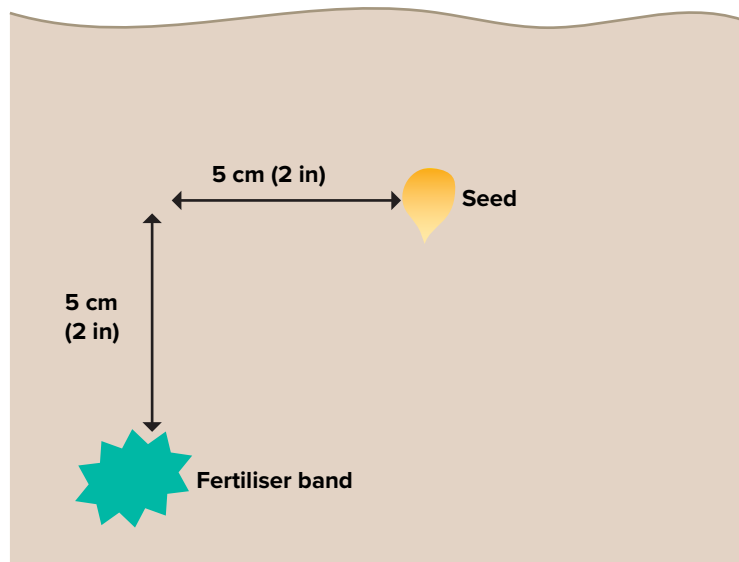
Advances in seed enhancements, such as pelleting, priming and pre-germination, require increased scrutiny of seed quality before and after the enhancement process. New developments in computer imaging for improved purity and germination–vigour analyses are being developed. These novel approaches to seed-quality assessment become important as new genetic improvements are conveyed in the seed at increased cost to the grower.<sup>16</sup>

**2.3.1 Seed size**

Seed has size and shape gradings. Maize seed varies from 4400 seed/kg (small) to 2500 seed/kg (large). Refer to bag for an exact seed count.<sup>17</sup> Seed shape consists of rounds or flats. Flat seed is generally best in plate seeders, while round seed is preferred by air seeders. There is no difference between the crops produced by these seed shapes. Information on the germination percentage and the date the test was conducted should also be with the bag.<sup>18</sup>

**2.3.2 Safe rates of fertiliser sown with the seed**

Maize does not tolerate high levels of fertiliser in contact with the seed, so care should be taken to avoid this at planting. A starter fertiliser (small percentage of nutrient requirement) may be placed with the seed if low soil temperatures or cool, waterlogged soils are likely after planting. This provides the seed with a ready nutrient source. The starting fertiliser should not exceed 5 kg nitrogen and 10 kg phosphorus/ha when sown in 90-cm rows. The application of a compound fertiliser (NPK) drilled 5 cm to the side of or below the seed is preferable (Figure 3).<sup>19</sup>



**Figure 3:** Application of a compound fertiliser (NPK) drilled 5 cm to the side of the seed is preferable.

16 MB McDonald (1998) Seed quality assessment. *Seed Science Research* 8, 265–276, <http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=1356024&fileId=S0960258500004165>

17 QDAF (2012) Varieties and planting of maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting>

18 QDAF (2012) Varieties and planting of maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting>

19 QDAF (2012) Nutrition, irrigation and weeds for maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/nutrition-irrigation>

## SECTION 2 MAIZE

TABLE OF CONTENTS

FEEDBACK

### MORE INFORMATION

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[Urea. Fertiliser Facts. Incitec Pivot Ltd.](#)

[Nutrition, irrigation and weeds for maize. Department of Agriculture, Fisheries and Forestry Queensland.](#)

Potassium should not be placed in the seed trench at sowing, because only minor amounts are allowable with seed and these are not cost-effective. Below 5 cm, however, growers can place as much as required, similar to nitrogen.



**i** MORE INFORMATION

[AM Smith \(1970\) Effect of fungicides on the germination of maize seed after storage.](#)

[Australian Pesticides and Veterinary Medicines Authority.](#)

# Planting

## 3.1 Seed treatments

Use of a seed treatment at planting is recommended for maize because early-planted crops usually encounter the most pressure from insects and diseases; false wireworm in particular are generally in abundance in the early part of the season.<sup>1</sup>

### IN FOCUS

Researchers have examined the effect of seed treatments with three fungicides, Ceresan (2.3% phenyl mercury acetate and 0.4% ethoxy mercury silicate), Coversan (96% tetrachloro-p-benzoquinone) and Panogen (2.2% methylmercury dicyandiamide), on the germination of two cultivars of maize stored for up to 12 months after treatment. None of the treatments affected the germination of maize.<sup>2</sup> This treatment is not currently registered.

## 3.2 Soil type

Maize will grow on a wide range of soil types, providing the soils are well drained. A pH range of 5–8 can be tolerated but best growth is achieved in the range of pH 5.6–7.5.

Maize does not grow well in saline soils. Yield reductions of ≥10–20% can be experienced if soil extracts have an electrical conductivity (EC) of 2.0–4.0 dS/m. Yield decline is likely if irrigation water has an EC of >1.5 dS/m. Seedling and flower growth is most sensitive to salinity.<sup>3</sup>

1 Early pest of sorghum and maize. Agronomy Topics. Pacific Seeds, <https://www.pacificseeds.com.au/agronomy-tools/summer-solutions.html>

2 AM Smith (1970) Effect of fungicides on the germination of maize seed after storage. *Australian Journal of Experimental Agriculture and Animal Husbandry* 10, 174–175, <http://www.publish.csiro.au/paper/EA9700174.htm>

3 QDAF (2012) Varieties and planting of maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting>



### 3.3 Time of sowing

The decision about when to plant should be based on suitable soil temperature in combination with the last expected frost, a full profile of moisture particularly for dryland production, avoiding flowering during expected peak temperature periods, and therefore working back to a suitable planting date. Consequently, for a late plant, try to time flowering after the main summer heat but early enough to beat the first expected frost. Later planted crops are subject to higher insect and disease pressure.

Early-planted maize shades the soil earlier in the season, thus reducing water lost to evaporation; it also reaches the most critical stage of silking with more water left in the subsoil, along with a deeper root system capable of extracting more available water.<sup>4</sup>

Earlier sowing periods provide advantages; these include having more stored water available to following crops, either double-cropped or the following summer crop.

Sowing time is governed by:

- soil temperature
- soil moisture
- targeted flowering date and cultivar.

#### 3.3.1 Soil temperature

Although maize will germinate when the soil temperature reaches 10°C, it is advisable not to plant until the ground temperature reaches 12–14°C at 09:00 (9am) at a depth of 10 cm for at least 3 or 4 consecutive days. Even at 12°C, maize will take up to 2 weeks to emerge, and the longer it takes the more prone the seedling is to insect attacks and damping-off diseases.

The young maize plant will tolerate light frosts as long as the growing point is still below the soil surface, which is about the 6–8-leaf stage. Leaves will still be burnt off but will be quickly replaced with new ones. If a frost affects the growing point, it will normally tiller and will require a replant.

An early frost on late-planted maize can have a major effect if it is severe and the crop is not at physiological maturity (black layer).

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<sup>4</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09. Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

## SECTION 3 MAIZE

TABLE OF CONTENTS

FEEDBACK



Hybrids of different maturities are recommended for different latitudes (Table 1). In Australia, except for the southern areas, there is a wide planting window and maturity is not as critical as it is in the USA.

**Table 1: A guide to the general maturity plantings in Australia.**

Location	CRM
Tasmania, Gippsland and Western Districts	Under 100 CRM
NE Vic., SA and southern tip of WA	97–113 CRM (can be slightly longer for silage)
MIA, Lachlan and Macquarie Valleys	105–118 CRM (longer end of range for grits & silage)
Liverpool Plains and northern NSW	108–118 CRM
Sydney basin, mid/north coast, Northern Rivers of NSW	115–126 CRM
Darling Downs and Burnett	108–120 CRM
Central Queensland and Callide Dawson	111–118 CRM
North Queensland	118–130 CRM

CRM, Comparative relative maturity

Maize does not germinate at soil temperatures <10°C. Commence sowing when the 9am EST soil temperature at sowing depth reaches 12°C and is rising. For irrigated crops, the temperature of water used for pre-irrigation or watering-up can influence sowing time. If watering-up, allow for a decrease of 3–4°C in soil temperature following watering. The rate of seedling emergence increases with increasing soil temperature. At 12°C, emergence will occur in 14 days, whereas at 25°C emergence occurs in 4–5 days.

Sowing time and hybrid selection determine whether the crop will be exposed to the hot conditions during pollination, which can significantly reduce yield. Tasselling and silking occurs ~8–10 weeks after planting for mid-maturity hybrids. Temperatures >35°C at this time lead to pollen blasting, resulting in poor kernel set and yield loss. Moisture stress is also more likely to occur on hot days. In the inland areas, temperatures >35°C are most likely to occur between mid-December and mid-February. Staggered sowing times mitigates the risk of large yield penalties due to pollen blast.

Early sowing balances the risks of frost soon after emergence and excessive heat at flowering. Cold conditions after emergence will slow seedling growth and foliage may turn purple, as phosphorus (P) is less available at low soil temperatures; however, crops recover as conditions warm up. Young crops can generally survive one or more frosts because the growing point does not appear above the soil surface for 3–4 weeks after emergence.

Late sowing avoids excessive heat at flowering but increases the risks of insect attack by *Helicoverpa* and mites, disease in late summer, and slow dry-down periods in cool, wet autumns. For these reasons, quick-maturing hybrids are favoured for late sowings.

The north and central coast region has the longest growing season for maize in Queensland. However, early sowing opportunities tend to be limited to irrigated situations because spring is commonly dry. Main sowing is usually delayed until mid-November through December. Coastal rain-grown crops should be planted so that the critical period from 2 weeks before to 4 weeks after silking occurs when there is a high probability of good rain.<sup>5 6</sup>

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[A Ringrose-Voase \*et al.\* \(2003\) Deep drainage under different land uses in the Liverpool Plains catchment.](#)

[Agricultural Resource Management Series, NSW Agriculture.](#)

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5 Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09. Pacific Seeds Pty Ltd. <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

6 QDAF (2012) Varieties and planting of maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting>



### 3.3.2 Planting moisture requirement

Dryland maize should be planted on a full soil moisture profile. Irrigated crops should be irrigated pre-plant and then, if using flood irrigation, not watered until 6 weeks old (pre-tasselling). If conditions are hot and dry, a quick flush 2–3 weeks after emergence may be required.

Maize is not tolerant of waterlogging especially during seedling and flowering stages.<sup>7</sup>

### 3.3.3 New South Wales

On the south coast and the tablelands of NSW, the safe time to sow is October and November. This is due to the risk of late frosts at the beginning of the season and/or early frosts towards the end of the season. See Table 2 for further detail.<sup>8</sup>

**Table 2:** Suggested sowing times for maize in NSW production areas.

Region	Early plant								Late plant																			
	Aug				Sept				Oct				Nov				Dec				Jan				Feb			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Northern Inland			>	>	☉	☉	☉	☉	☉	☉	☉	☉	<	<					>	>	☉	☉	☉	☉	<	<		
Central Inland					>	>	☉	☉	☉	☉	☉	☉	<	<														
Southern Inland							>	>	☉	☉	☉	☉	☉	☉	<	<												
Tablelands							>	>	☉	☉	☉	☉	☉	☉	<	<												
North and Central Coast			>	>	☉	☉	☉	☉	☉	☉	☉	☉	☉	☉	☉	☉	☉	☉	☉	☉	☉	☉	☉	☉	<	<		
South Coast							>		☉	☉	☉	☉	☉	☉	☉	☉	<	<										

>, Earlier than ideal; ☉, optimum sowing time; <, later than ideal. Note that the Liverpool Plains of NSW is prone to frost at both early and late sowing stages than Boggabri and other northern NSW areas

### 3.3.4 Queensland

In southern Queensland, mid-September to mid-October is the premium time to sow. December provides another suitable opportunity, especially for dryland crops (Table 3). In Moreton, maize is often successfully planted as early as mid-August. Latest plantings in these areas would occur in early to mid-January, because of likelihood of disease development in late summer–autumn.

A minimum soil temperature of 12°C is needed at seed depth before attempting sowing in mid-September. Cold conditions after establishment will slow the growth of seedling maize, often causing foliage to turn purple, probably due to reduced P availability at lower soil temperatures. However, once temperatures begin to rise again, the crop continues to grow normally. Planting at this time will avoid flowering in midsummer heat.

December plantings flower after midsummer heat but may be more susceptible to diseases such as rust, leaf blights and wallaby ear, and perhaps Fusarium kernel rots.

Hot, dry weather can kill pollen as it is shed from the tassel, or induce uneven flowering. For example, silk emergence from the cob may be delayed and occur when pollen is no longer being shed from the tassel, resulting in poor seedset on the tip of the ear.

In Central Queensland, some waxy and grit maize is planted in mid-August to early September, especially under irrigation. However, the main crop is planted late

<sup>7</sup> QDAF (2012) Varieties and planting of maize. Department of Agriculture, Fisheries and Forestry Queensland. <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting>

<sup>8</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries. <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

## SECTION 3 MAIZE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

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January to first week in March, to avoid heat stress, which can reduce pollen viability at flowering time.

In Far North Queensland, irrigated maize is planted in late July to August. Later plantings occur in late November to late January, with the optimum time being mid-December. Successful plantings have been made in late February, but these are the exception, and this time is not recommended.<sup>9</sup>

**Table 3: Suggested sowing times for maize in Queensland production areas.**

Region	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
North Qld							*	
Central Qld		i i						
South Burnett				h h		d d d d d		
Darling Downs					r r r			
Moreton					d d d			

Optimal planting time; preferred planting time; d, higher disease risk; r, suitable for dryland crops; i, satisfactory under irrigation; \*, late planting not recommended; h, high risk of heat stress during flowering

## 3.4 Targeted plant population

Most irrigated crops are planted in rows ranging from 76 to 100 cm, with the majority of planters set up for 100-cm row spacing. Under irrigation and higher yielding situations, the narrower rows are generally agreed to have a slight yield advantage.

On the other hand in more marginal dryland conditions, wider rows or a skip-row configuration have shown yield responses in some years. Single skips on rows 75 cm to 1 m have shown some advantage (keeping the same population as a solid plant), whereas double-skip rows of 1-m row spacing are too wide, with moisture remaining at the end of the season between the rows.

Growers may benefit from trialing different row configurations before deciding on one pattern because different results may be seen between hybrids and different seasons.<sup>10</sup>

### 3.4.1 Plant populations

Maize grown in Australia is planted under a huge range of conditions from the high-input, full irrigation areas of southern Australia to the very marginal dryland areas of Central Queensland. As a result, planting rates vary from 100,000 to 20,000 kernels/ha depending on environments and conditions.

Total water usage in a maize crop is not directly related to plant population, because water is lost by both plant respiration and direct evaporation from the soil. Until the canopy shades the total ground, losses to evaporation will occur.

Higher plant populations shade the ground earlier and reduce the amount of water that is wasted by direct evaporation while the surface is moist. With higher populations, plants shade each other more, which reduces leaf temperatures and the amount of water transpired by the leaves. Higher plant populations will deplete available soil water at a faster rate and irrigation frequency will need to be increased. Higher populations speed up maturity by up to 7 days.

The primary function of a maize canopy is to intercept light. Light that reaches the soil surface is lost, or worse still reduces potential photosynthesis and hence yield (latitude and therefore daylength is now becoming increasingly important). Once

<sup>9</sup> QDAF (2012) Varieties and planting of maize. Department of Agriculture, Fisheries and Forestry Queensland. <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting>

<sup>10</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09. Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>



light is intercepted, it must be used as efficiently as possible and this is a function of leaf angle. Flat horizontal leaves do the best job of intercepting light but use it least efficiently. Vertical leaves are poorest at intercepting light but use it most efficiently. The ideal plant type would have horizontal lower leaves and erect upper leaves.

The physical makeup of the plant tells us that with an established population of >60,000–70,000 plants/ha, competition for light becomes just as important as moisture and nutrient availability. This is a main reason for barren plants in higher population crops, especially with hybrids that have more horizontal leaves than vertical leaves.

In summary, calculation of the correct plant population should be based on the following variables: selection of individual hybrid—this may also influence row spacing and longer season hybrids generally require fewer plants than shorter season hybrids; the market you are aiming at—slightly lower population will give a bigger kernel for the grit market, silage growers may consider a few more plants for higher dry matter production; latitude; climate; and planting time.

When doing the final calculation to determine the planting rate to achieve the desired established plant population, you need to allow for:

- actual seed germination
- whether the soil temperature and moisture optimum
- whether any ground insects are present
- type of planter being used and its accuracy
- groundspeed of planter.

As a guide, a reasonable field establishment is ~80%, which allows for actual seed germination (e.g. 90%) and 10% loss for the other variables.<sup>11</sup>

Many factors including soil moisture, climatic conditions, soil fertility, hybrid and end use determine the best plant population for a crop. Dryland crops in drier areas should have lower plant populations than irrigated or high-rainfall area crops (Tables 4 and 5).

Quick-maturing hybrids produce smaller plants and so they should be sown in higher populations. Conversely, slow-maturing varieties generally produce larger plants so usually grow best when sown at lower densities. However, within any maturity group, hybrids have different tolerances to high plant populations, with the more tolerant having better resistance to lodging, a low percentage of barren plants and good timing of silking with pollen shedding. Silage crops need higher populations than grain crops. See Table 4 below for general recommendations. Refer to seed companies for additional information.

If the only available planting window will expose the crop to high temperatures during tasselling, silking and early cob formation, reducing the plant density can reduce moisture stress and mycotoxin risk.

Maize is highly responsive to plant population and plant uniformity, meaning the sowing operation is critical for high yields, so care must be taken. Precision-planting equipment, such as vacuum seed metering systems, is preferred. Sow at a uniform depth to ensure uniform emergence and achievement of the target plant stand. Opportunities to increase speed at sowing should only be used where the precision of the operation is not compromised.<sup>12</sup>

<sup>11</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09. Pacific Seeds Pty Ltd. <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directrouter.com>

<sup>12</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

**Table 4:** Recommended plant populations for grain and silage crops in NSW.

Moisture availability	No. of plants per ha	
	Grain	Silage
Irrigated—all regions	60–80,000	70–100,000
Dryland		
Coastal	45–55,000	50–65,000
Tablelands	40–45,000	50–60,000
Northern Plains	20–30,000	

**Table 5:** Recommended plant populations (no. of plants/ha) in Queensland.<sup>13</sup>

	Dryland	Irrigated
North Queensland:	45–55,000	60,000
- Atherton, Tolga, Kairi	40,000	60,000
- Kaban, Walkamin, Mareeba, Lakeland	50,000	
- Wet tropical coast		
Central Queensland	20–40,000	50–80,000
South Burnett	25–30,000	55–70,000
Darling Downs – north	25–30,000	60–75,000
Darling Downs – central/south	40–45,000	60–75,000
Moreton (Lockyer/Fassifern)	45–60,000	60–75,000

This table is a guide only. The recommended population for a specific variety should be obtained from the seed company. If growing for silage, use the higher population ranges<sup>14</sup>

### 3.4.2 Planting rate

Table 6 shows planting rates (kg/ha) for various seed sizes when using 90-cm row spacing. Average seeding rates are based on 85% germination rate and 100% emergence rate.

**Table 6:** Sowing rates to achieve desired plant population using various seed sizes.

Desired plant population per ha	Number of seeds per kg:				Average seed spacing, 90-cm rows
	2500	3000	3500	4000	
	Seed sowing rate kg per ha				
15,000	7	6	5	4.5	63 cm
20,000	9	8	7	6	47 cm
25,000	12	10	8	7	37 cm
30,000	14	12	10	9	31 cm
50,000	24	20	17	15	19 cm
60,000	28	24	20	18	16 cm

Should different spacing be used between rows, the following calculation can be used:

- Planting rate = desired population ÷ (no. of seeds/kg × germination% × emergence%)

<sup>13</sup> QDAF (2012) Varieties and planting of maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting>

<sup>14</sup> QDAF (2012) Varieties and planting of maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting>



where planting rate is seed planted (kg/ha); desired population is number of plants per ha (e.g. 40,000); no. of seeds/kg is indicated on the seed pack (e.g. 3000); germination% is indicated on the seed pack (expressed as a decimal, e.g. 85% is 0.85); and emergence% is, for example, 90%.

Working example:

- Planting rate (kg/ha) =  $40,000/3000 \times 0.85 \times 0.90$
- Planting rate = 17 kg seeds/ha

A ready-reckoner to obtain emergence percentage (%):

- precision planters 60–90%
- other planters with press wheels 50–70%
- other planters with no press wheels 30–50%
- or use a figure from your own experience.

Calculating seed spacing along the row (this calculation is used to calibrate the seed drill to sow at the required rate):

- Distance between seeds in the row (m) =  $10,000/\text{planting rate (kg/ha)} \times \text{no. of seeds/kg} \times \text{row width (m)}$

Working example:

- Distance between seeds in the row (m) =  $10,000/17 \times 3\,000 \times 0.9$
- Distance between seeds in the row = 0.21 m (or 21 cm)<sup>15</sup>

### 3.4.3 Row spacing

Row spacing is commonly 75–110 cm. Width is ultimately determined by the available planter, tractor, harvester and other equipment. Narrow rows are an advantage when there is good in-crop rainfall or irrigation, high fertility and high plant populations. In such conditions, narrower rows will usually produce slightly higher yields because plants are more evenly spaced.

For dryland production in drier areas such as the North-West Plains, single- or double-skip on 100-cm rows is suggested so that soil moisture is conserved for grainfill. Trials at Moree suggest that, in moisture-stressed conditions, there may be no advantage of double-skip over single-skip configurations because of the inability of lateral roots to extract moisture from the centre of a double-skip. With skip-row configurations, use the same target plant population as for solid planting. This means, for example, that the in-row plant population in double-skip rows will be twice that in solid planting.<sup>16</sup>

Planting seed varies from year to year because of seasonal influences and growing conditions. Planting seed can be bought in six categories, all in 72,000-kernel bags: small flats, small rounds, medium flats, medium rounds, large flats and large rounds.

Most vacuum planters have a tolerance to a range of seed sizes, but it is advisable to keep on hand a range of planting plates, as your preferred size may not always be available.

The same seed size can vary in kernel count per kg from year to year, and air pressure on vacuum planters should be adjusted accordingly.<sup>17</sup>

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<sup>15</sup> QDAF (2012) Varieties and planting of maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting>

<sup>16</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

<sup>17</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09. Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>



### 3.5 Sowing depth

Under ideal conditions, a sowing-depth range of 3–6 cm is recommended, although if soil temperatures are relatively warm, maize will still emerge from a depth of up to 9 cm if moisture is available. Growers in the southern areas, who water up as opposed to planting into pre-watered fields, do not need to plant at this depth and may choose to sow the seed at ~2–3 cm.<sup>18</sup>

### 3.6 Sowing equipment

Precision planters are the main type of planters used in the maize industry, with very little use of traditional combines or seed drills where fluted rollers and coulters give uneven seed distribution.

Compared to other grain crops, maize is generally planted at a much lower population, and it is therefore crucial to have even plant stands, which can be achieved with precision planters (Figure 1).

In addition, maize does not compensate by tillering in the way that a crop of sorghum does, so it is essential to get an evenly spaced crop.

Other advantages of precision planters are the even planting depth, ability to apply starter fertiliser away from the seed, and the fact that insecticide boxes and spraying equipment on the planter means that both insecticides and herbicides/liquid fertilisers can all be applied in the one operation. All precision planters are fitted with press-wheels, which enhance seed–soil contact.

New growers without adequate planting equipment, or growers not using precision planters, should consider using a contractor with a precision planter.

Planting speed has an impact on the spacing of the seed, and the slower the better. Groundspeeds of 5–6 km/h are ideal, causing less seed bounce than speeds of 8–10 km/h.<sup>19</sup> However, excellent technology is available now with, planters using vSets to get better even establishment.



**Figure 1:** A precision-planted maize crop.

Photo: Pacific Seeds

<sup>18</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09. Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

<sup>19</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09. Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

### 3.6.1 Evenness of establishment

Precision planters give more even plant spacing in the row. It is important to avoid seed bounce in seed tubes and in seed furrows to avoid gaps and thick patches in a row. Uneven plant establishment and uneven plant spacing both effect grain size and yield severely. This is more critical for gritting maize than for feed maize.<sup>20</sup>

<sup>20</sup> QDAF (2012) Varieties and planting of maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/varieties-planting>



# Plant growth and physiology

A broad understanding of the growth of a maize plant will allow us to consider when the critical growth stages occur and what the nutritional and water requirements are at those times.

Often, farmers spend a considerable amount of money on fertiliser, cultivation and watering their crop only to end up with an average yield. They have used the optimum level of inputs but have not achieved the optimum yield, usually because of poor timing of inputs or poor crop management.

This can be due to a lack of knowledge (or clear understanding) of the growth habits and requirements of a maize crop. Understanding a maize plant's development and its critical growth stages is essential to achieving high yields and obtaining maximum profitability.



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[LJ Abendroth \*et al.\* \(2011\) Corn growth and development. Iowa State University Extension and Outreach.](#)

[Growth stage estimator. Du Pont Pioneer.](#)

The development of a maize plant and its requirements are shown in Figure 1. All maize plants follow the same general pattern of development, but differences in the time taken for the various growth stages depend primarily on hybrid maturity (given similar conditions).

The times, heights and comments indicated in Figure 1 are for a hybrid with a comparative relative maturity (CRM) of ~120 days.<sup>1</sup>

<sup>1</sup> Growth potential. Corn growers' workshop. Pioneer Hi-Bred Australia. [http://www.pioneer.com/CMRoot/International/Australia\\_Intl/Publications/Corn\\_Workshop\\_Book.pdf](http://www.pioneer.com/CMRoot/International/Australia_Intl/Publications/Corn_Workshop_Book.pdf)

Maize development	Weekly requirements (as percentage of total need)			
	% N	% P	% K	% Water
<b>Maturity</b>				
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
<b>Silking</b>	12	15	8	12
<b>Tasseling</b>	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
<b>Emergence</b>	less than 1	less than 1	less than 1	less than 1

Figure 1: Maize development.

Source: Pioneer

## 4.1 Germination and emergence

### 4.1.1 Germination—VE stage

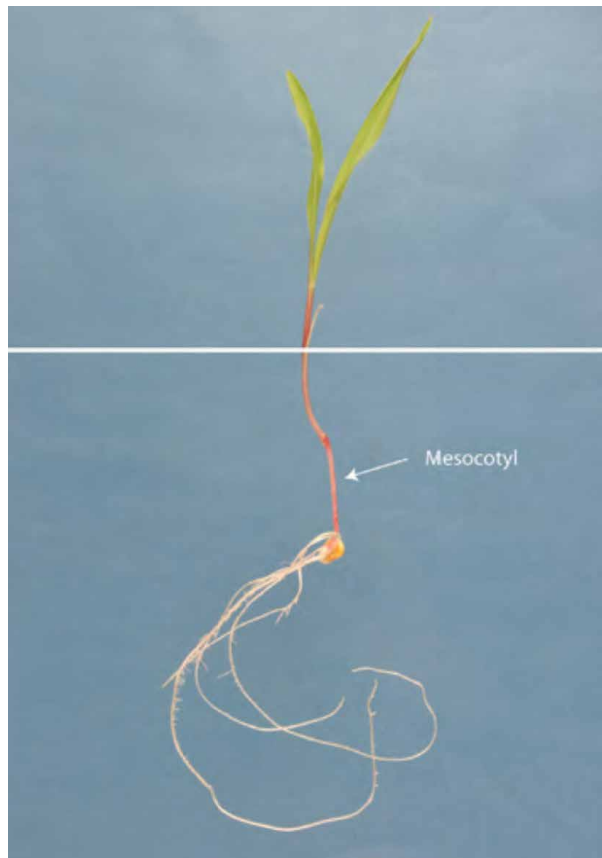
When the maize kernel is planted in moist, warm soil, water is absorbed through the seed coat (this process is called imbibition) and the kernel begins to swell. The kernel accumulates ~30% of its dry weight as water before enzymatic activity in the embryo begins.

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 specialized 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 2).



**Figure 2:** *The germinating kernel.*

Photo: Lowan Turton



**Figure 3:** *The developing seedling.*

Photo: Lowan Turton

The first seedling root (the radicle) is soon followed by several other seminal or seed roots (Figure 3). 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 2–3 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 ~3 cm below the soil surface until ~3 weeks after emergence.



Between the point of attachment to the kernel and the crown is the mesocotyl (Figure 3), 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 2–3 cm 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.<sup>2</sup>

### 4.1.2 Emergence—VE stage

The coleoptile emerges from the soil 6–10 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 4). 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, because 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).<sup>3</sup>



**Figure 4:** Emergence.

Photo: Kieran O'Keefe

<sup>2</sup> K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)

<sup>3</sup> K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)





### 4.1.3 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 and 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.<sup>4</sup>

#### 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.<sup>5</sup>

#### 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.<sup>6</sup>

#### Temperature

##### Germination

Germination depends on temperature. Germination is greatly reduced if the soil temperature is <10°C. Maize should be sown when the soil temperature (at sowing depth) at 09:00 (9am) (EDST) is >12°C and increases over the following days. At these relatively low temperatures, seedling emergence will be very slow (≥14 days); at 25°C, seedlings emerge in 4–5 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 in a range of 10°–30°C, the growth rate increases. Below 10°C there is little growth, and >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 the daily maximum temperature is outside the 10°–30°C range. If this occurs, the values 10 and 30 are substituted as the minimum and maximum values, respectively.<sup>7</sup>

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

<sup>4</sup> K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Proccrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Proccrop-maize-growth-and-development.pdf)

<sup>5</sup> K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Proccrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Proccrop-maize-growth-and-development.pdf)

<sup>6</sup> K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Proccrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Proccrop-maize-growth-and-development.pdf)

<sup>7</sup> K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Proccrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Proccrop-maize-growth-and-development.pdf)



SECTION 4 MAIZE

TABLE OF CONTENTS

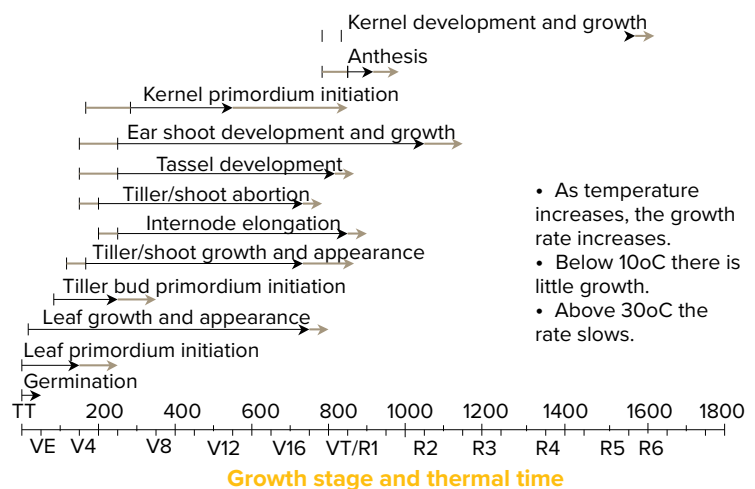
FEEDBACK



Figure 5 shows the relationship between the growth stage and thermal time (= number of growing degree-days) in the maize plant.

**Table 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 5:** *Relationship between growth stage and thermal line (growing degree-days) in the maize plant.*

Source: McMaster et al. 2005

### 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 <20%. During germination, water softens the seed coat to make it permeable to oxygen, so dry kernels absorb almost no oxygen.

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 in fact, they run out of oxygen and die.<sup>8</sup>

<sup>8</sup> K O’Keeffe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)

## Nutrition

Because the kernel has stored within it all the essential nutrients that it needs to begin growing, nutrient shortages are not an issue in the first few days. However, as the roots begin to take over nourishing the young plant, shortages of elements such as nitrogen (N) and phosphorus (P) can slow growth and development.

A soil test should be done 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 modern maize planters. Apply mixed fertilisers (N, P and/or potassium (K)) 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.<sup>9</sup>

## 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 press-wheels (Figure 6).

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 N is needed because some N is tied 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 N tie-up.<sup>10</sup>



**Figure 6:** *The sowing operation.*

Photo: Kieran O'Keefe

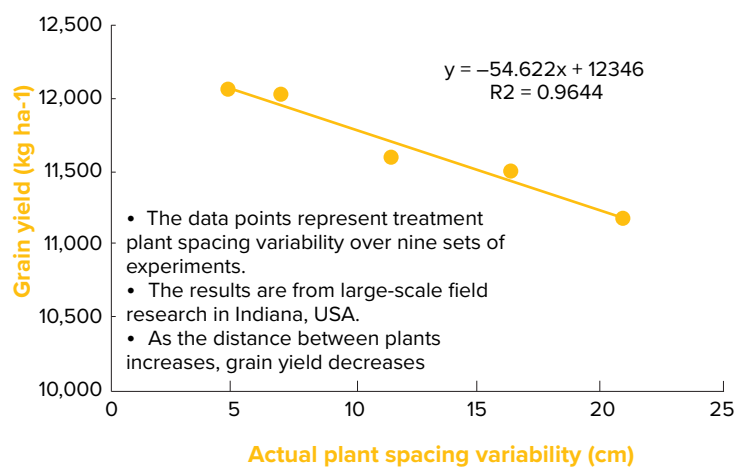
<sup>9</sup> K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Proccrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Proccrop-maize-growth-and-development.pdf)

<sup>10</sup> K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Proccrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Proccrop-maize-growth-and-development.pdf)

### Sowing depth

Seeds should be sown at a depth where there is sufficient soil moisture for seedling emergence. The ideal depth is 4–5 cm, although seeds may be sown as deep as 9 cm. Deeper sowing slows seed emergence. It does not create a deeper root system or enhance the plants 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 7.<sup>11</sup>



- 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 7:** Relationship between maize grain yield and measured plant spacing.

Source: Nielsen 2006

### Plant population

Each hybrid grown in a particular location will have an optimum range in plant population to maximise yield.

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 >90%.

When calculating a sowing rate, allow an extra 5–10% for establishment losses under normal growing conditions. See Table 2. An even plant spacing is important to maximise yields (Figure 8).

**Table 2:** Recommended plant populations.

Moisture availability	No. of plants per ha	
	Grain	Silage
Irrigated, all regions	60–80,000	60–100,000
<b>Dryland</b>		
Coastal	45–55,000	50–65,000
Tablelands	40–45,000	50–60,000
Northern Plains	20–30,000	–

Source: NSW DPI

### MORE INFORMATION

N Moore *et al.* (2014) Summer crop production guide 2014. NSW DPI Management Guide.

<sup>11</sup> K O’Keeffe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)



**Figure 8:** Even spacing between plants is important to maximise yields.

Photo: Kieran O'Keeffe

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

#### *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 a result of greater root development.

#### *Type of hybrid sown*

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

#### *Planting pattern*

Rows are usually sown 75–110 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, because plants within the row can then be more widely spaced.





Evidence suggests that making the plant spacing uniform within the row is very important for maximising yield (refer to Figure 7).<sup>12</sup>

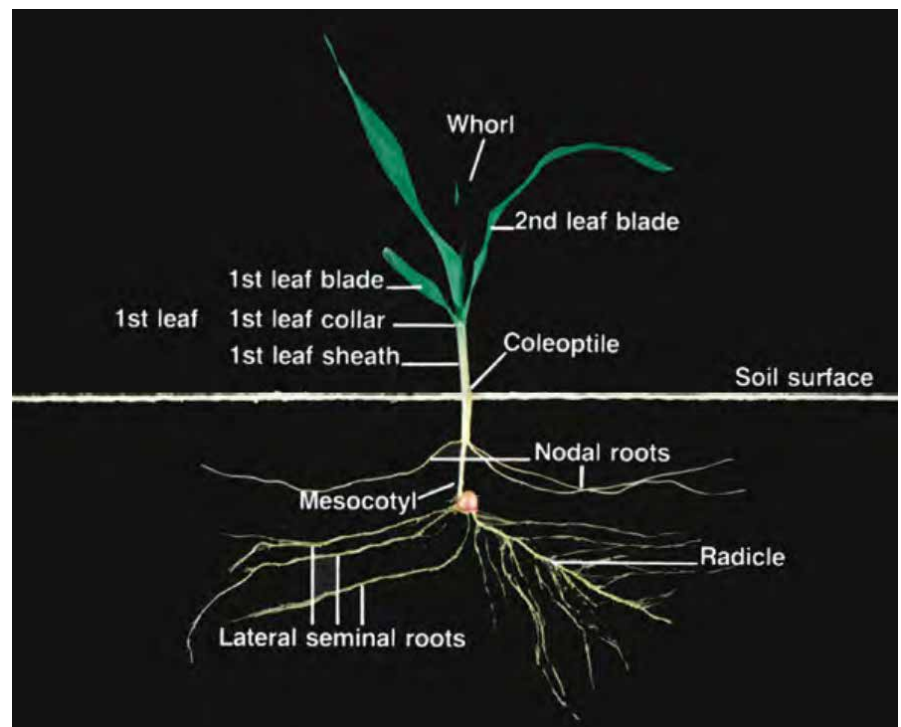
## 4.2 Vegetative growth

### 4.2.1 Vegetative Growth

#### V1–V2 stage

These growth stages occur about 1 week after the plant emerges (Figure 9). One or two leaves are visible on the stem and the primary root system is still relatively small.

Although the plant is using only small amounts of nutrients, they need to be in contact with the root system. Banded fertiliser placed underneath the seed will allow effective uptake.<sup>13</sup>



**Figure 9:** A V2 plant.

Source: Ritchie et al. 1992

#### V3–V5 stages

Two weeks after the plant emerges, the V3 stage begins (Figure 10). 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 the 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 ~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

<sup>12</sup> K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)

<sup>13</sup> K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)





point. Low 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.

### MORE INFORMATION

AM Massignam et al. (2001) Canopy architecture and nitrogen utilisation for biomass production: the contrast between maize and sunflower. Australian Agronomy Conference.

IKD Jaya et al. (2001) Modification of within-canopy microclimate in maize for intercropping in the lowland tropics. Australian Agronomy Conference.



**Figure 10:** A V3 plant.

Source: Ritchie et al. 1992

#### *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.<sup>14</sup>

#### **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, 700–1000 potential kernels or ovules are arranged on the cob, with about 35 per row and 12–24 rows.

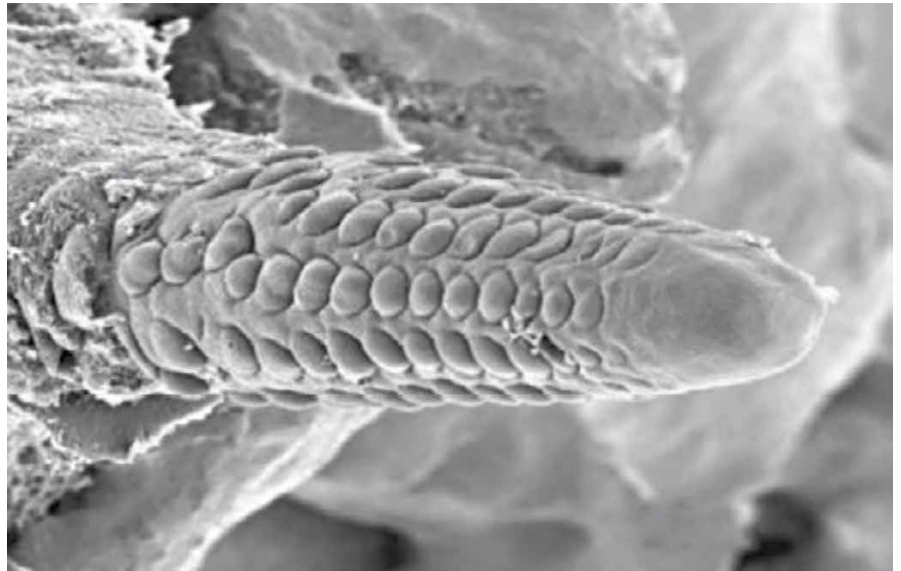
The timing of ear initiation varies with maize genetics. A general guideline is to determine which node contains the primary ear (the ear to be harvested) and then subtract 7 to give the stage number. This will give a reference point as to when ear initiation started. The V stage when ear initiation started is also when the number of kernel rows around the ear was being established.

For example, the maize line in Figure 10 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 11 has a CRM of 103. The primary ear is located on the V14 node. In general, maize lines with a CRM of 103–118 will produce the primary ear on the V13 or V14

<sup>14</sup> K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)

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.<sup>15</sup>



**Figure 11:** *Development of the primary ear at node 14.*

Photo: Antonia Perdomo, Pioneer Hi-Bred

### 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 and V8 stages in its life cycle.

The meristematic dome at the tip of the ear in Figure 11 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 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 it.

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 it instead of the normal 16, then the stress factor that caused this event was present at approximately V7.<sup>16</sup>

### V6 and V7 stages

Approximately 3 weeks after the plant emerges, the plant is at the V6 stage. The root system is well distributed in the soil and it 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.

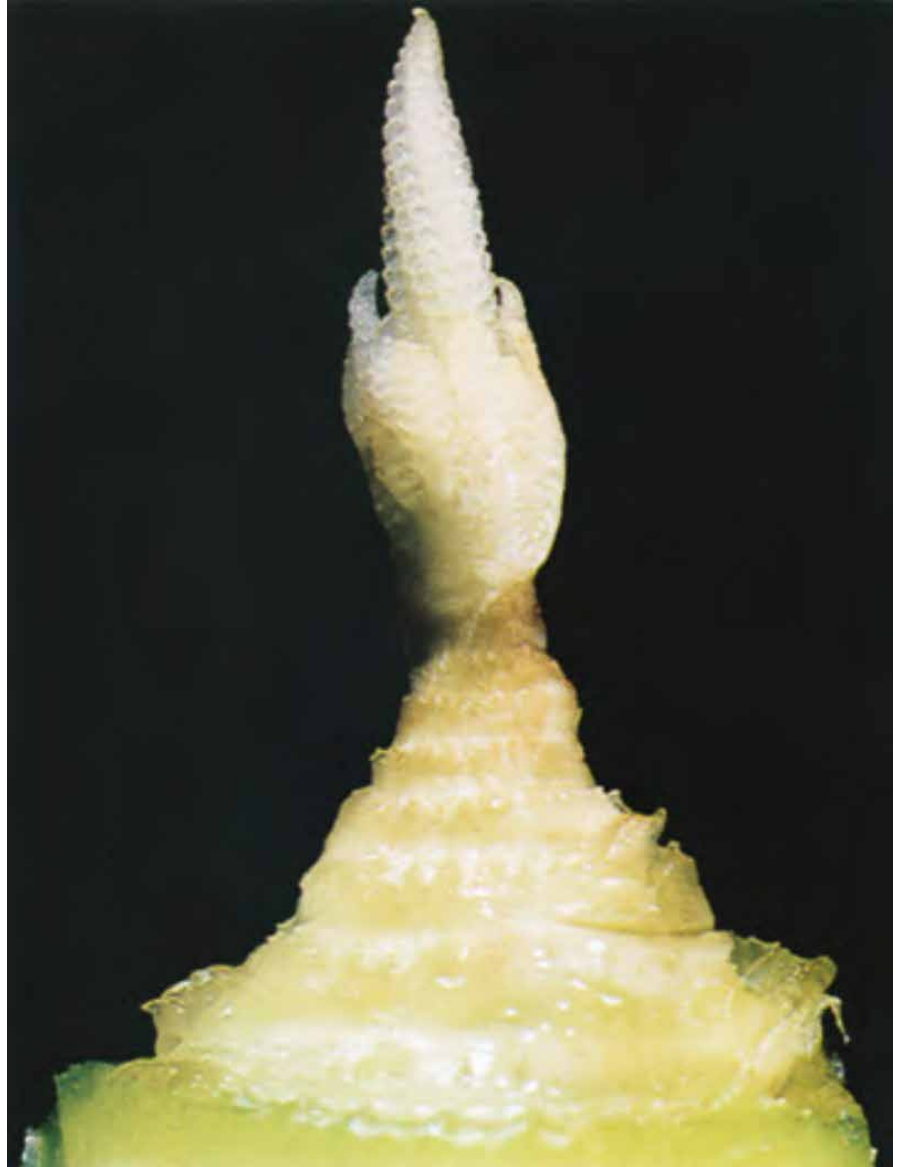
The plant is now absorbing greater amounts of nutrients. Row-applied fertiliser is less critical now, as nodal roots have spread throughout the soil. Nitrogen can be side-dressed up to V8 stage if it is placed in moist soil and excess root pruning and injury of aboveground plant parts are avoided.

<sup>15</sup> K O'Keeffe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)

<sup>16</sup> K O'Keeffe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)



Figure 12 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.<sup>17</sup>



**Figure 12:** *Tassel of a V7 plant.*

Source: Ritchie et al. 1992

### Establishing kernel numbers (V7–pollination)

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

<sup>17</sup> K O'Keeffe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)

With 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 they 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 13), appear to be due to a combination of environmental stresses—possible cold stress coupled with drought stress during a critical stage in ovule formation.<sup>18</sup>



**Figure 13:** ‘Beer-can’ ears.

Source: Strachan 2001

### V8 and V9 stages

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

The fourth whorl of nodal roots is elongating. Several ear shoots are present. A potential ear shoot will form at every aboveground 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. Highest yields are obtained with one cob per plant.

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 (by frost or hail) may result in 10–20% reduction in final grain yield.

Waterlogging at this or any earlier stage, when the growing point is below the ground, can kill the maize plants in a few days, especially if temperatures are high.<sup>19</sup> Figure 14 shows a V9 plant.

<sup>18</sup> K O’Keeffe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)

<sup>19</sup> K O’Keeffe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)





**Figure 14:** A V9 plant.

Source: Ritchie et al. 1992

### V10 and V11 stages

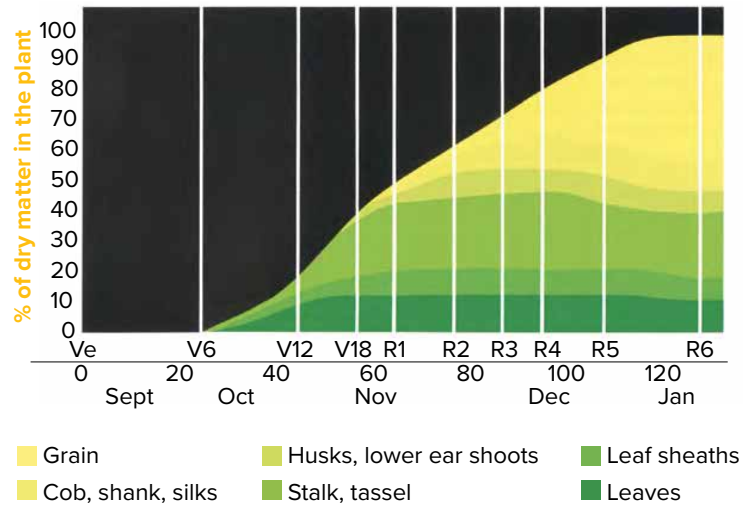
Approximately 5 weeks after the plant emerges, the V10 stage begins. The maize plant rapidly accumulates both nutrients and dry matter (Figure 15). The time between appearances of new leaves is shortened, with a new leaf now appearing every 2–3 days. Demand for soil nutrients and water is high in order 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 P and K, which do not move in most soils.

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

The length of time for the plant to develop through stages V10–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.<sup>20</sup>

<sup>20</sup> K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)





**Figure 15:** Dry matter accumulation at various stages in the maize plant.

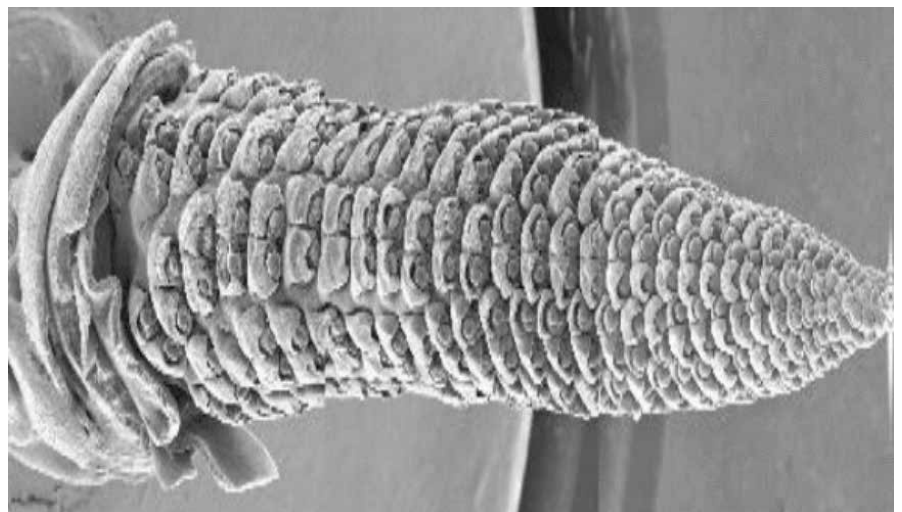
Modified Ritchie et al. 1992

### V12 and V13 stages

Approximately 6 weeks after the plant emerges, V12 stage begins (Figures 16, 17, 18). Brace roots (Figure 17) are developing from the fifth node and the first aboveground 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 16 shows an ear at the V12 stage from the same maize parent line as that in Figure 11. 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 some stress while the maize plant was around the V12 developmental stage may have occurred to cause it.<sup>21</sup>



**Figure 16:** Development of the primary ear: V12 stage.

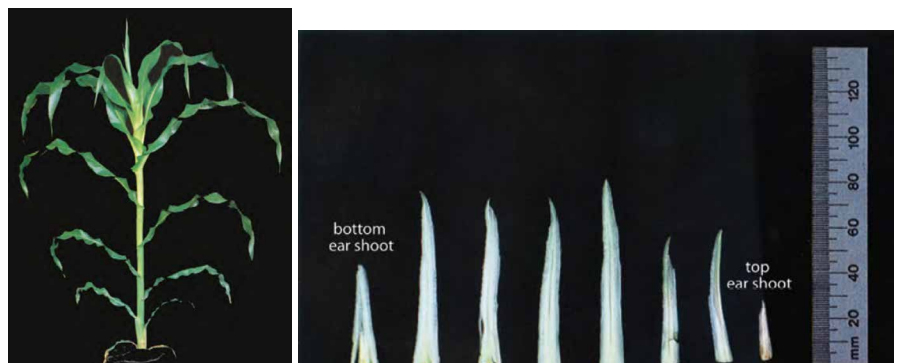
Photo: Antonio Perdomo, Pioneer Hi-Bred

<sup>21</sup> K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)



**Figure 17:** Brace roots.

Source: Ritchie et al. 1992



**Figure 18:** Left: plant at V12. Right: the top ear shoot is smaller than the lower ear shoots, but many of the upper ears are close to the same size.

Source: Ritchie et al. 1992

### V14 and V15 stages

About 7 weeks after the plant emerges, V14 begins. The maize plant at V15 (Figure 19) is only 12–15 days (~5 V stages) away from the start of reproductive growth (R1, 'silking'). This vegetative state 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 on the upper ears. Upper ear shoot development has surpassed that of lower leaf ear shoots. A new leaf stage can occur every 1–2 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.<sup>22</sup>



**Figure 19:** *Plant at V15.*

Source: Ritchie et al. 1992

### V16 and V17 stages

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 larger reduction in grain yield. This is also true for other types of environmental stresses (hail, high temperature, nutrient deficiencies). The 4-week period 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 >16 leaves. The tip of the tassel may also be visible by V17 in more prolifically leafing hybrids.<sup>23</sup>

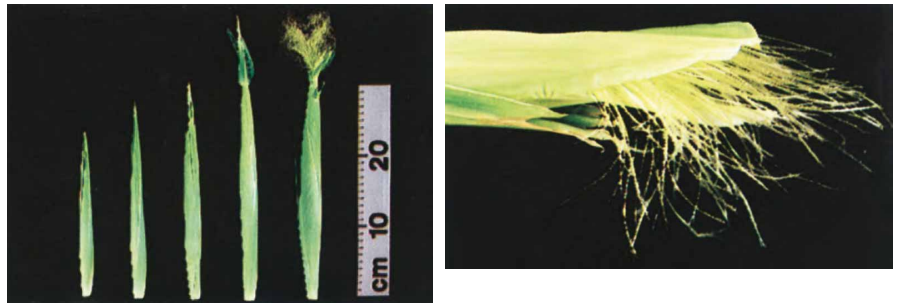
### V18 or VT stage

The vegetative plant is reaching full size in hybrids with prolific leafing (Figure 20). 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 aboveground 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, kernels will be missing on the ear, especially at the tip.<sup>24</sup>

22 K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Proccrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Proccrop-maize-growth-and-development.pdf)

23 K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Proccrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Proccrop-maize-growth-and-development.pdf)

24 K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Proccrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Proccrop-maize-growth-and-development.pdf)



**Figure 20:** Left: silks emerging in the later V stages. Right: upper ear shoot development.

Source: Ritchie et al. 1992

## 4.2.2 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 21).



**Figure 21:** A moisture-stressed crop.

Photo: Paul Newell

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.

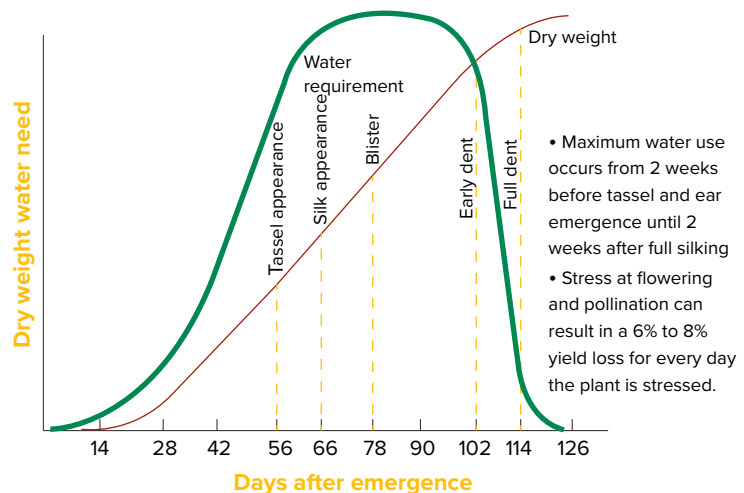
Moisture stress is particularly detrimental to grain yield if the stress occurs after tassel initiation, at flowering, and during mid-late grainfill.





Figure 22 shows that the water needs increase rapidly from ~2 weeks before tassel and ear appearance until ~2 weeks after the full silking and then decrease rapidly.

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



**Figure 22:** Maize plant water requirements at various times after sowing.

Source: Growing maize for profit, Pioneer Hi-Bred

### Waterlogging

Maize is very sensitive to waterlogging. Waterlogging causes low soil oxygen concentration, which limits root function and survival. The availability of N 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 depending on the growth stage at which the waterlogging occurs.

Waterlogging that occurs when the growing point is belowground 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.<sup>25</sup>

### 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 ~70–80% efficient, spray irrigation ~85–90% efficient, and drip irrigation ~90–95% efficient.

When maize is grown under irrigation, waterlogging is always a potential 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.

<sup>25</sup> K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)



### *Frequency*

How often you irrigate (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 monitor moisture at different depths throughout the profile (such as EnviroSCAN and C-Probe) have allowed accurate and continuous soil moisture monitoring (Figure 23). This technology also allows users access to 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 24 shows the soil moisture profiles of a maize crop on the Liverpool Plains, detected by probe, and Figure 25 shows the estimated irrigation requirements for a high-yielding crop at Gunnedah.



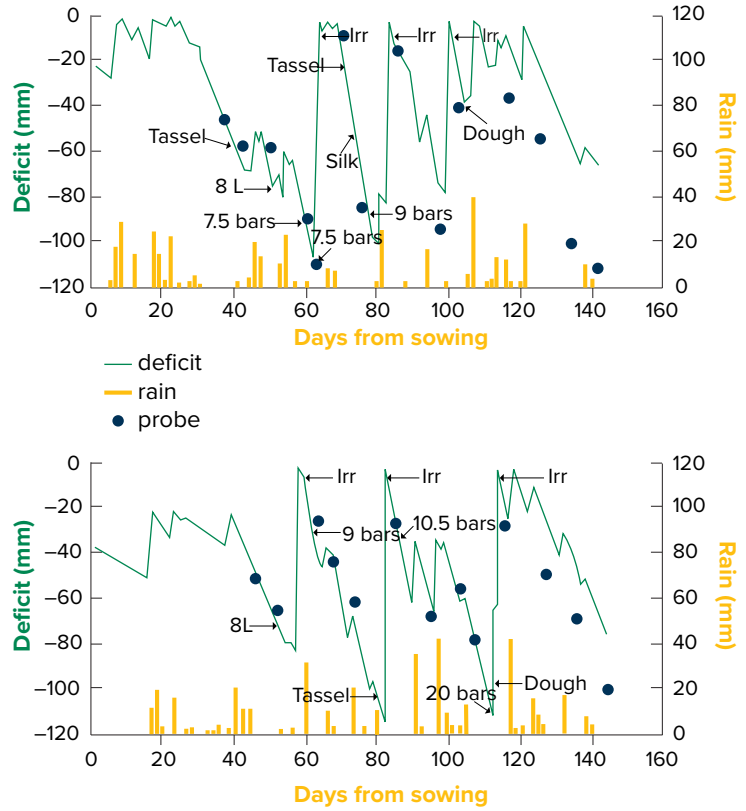
**Figure 23:** Soil moisture monitoring is an important tool in minimising crop stress.

Photo: Kieran O'Keefe

SECTION 4 MAIZE

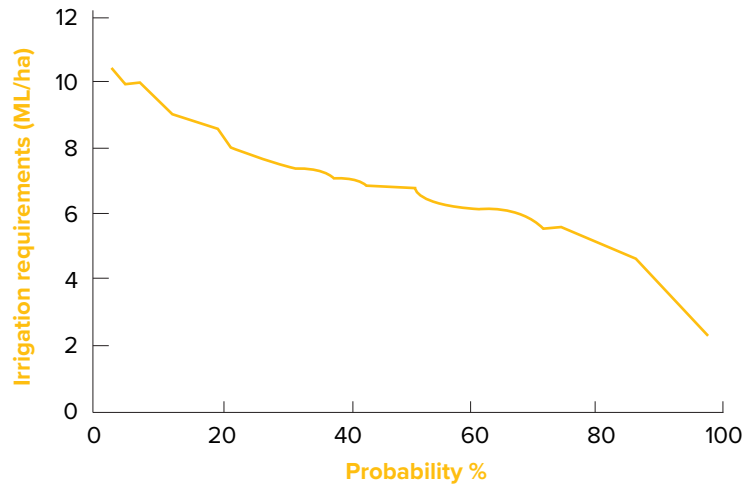
TABLE OF CONTENTS

FEEDBACK



**Figure 24:** Soil moisture profiles for a maize crop on the Liverpool Plains, NSW, in the 1989–90 season. Top: a crop irrigated on schedule (90 mm deficit) just before tasselling. Bottom: a crop that suffered serious stress at tasselling (115 mm deficit) and a further stress at dough stage.

Source: Kaiser et al. 1997



**Figure 25:** Estimated irrigation water requirements for a high-yielding crop at Gunnedah based on historical weather data and assuming an irrigation efficiency of 75%. In 50% of seasons, 6.8 ML/ha is needed. In 20% of seasons (1 in 5 years), 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

**i MORE INFORMATION**

[Growth potential. Corn growers' workshop. Pioneer Hi-Bred Australia.](#)

**Irrigation frequency**

Inland crops without rain generally require 1 irrigation every 10–12 days during the flowering and grain-filling stages. Hot dry weather can result in the irrigation interval shortening to 6–7 days. Crops in the north of NSW and southern Queensland may need 5 or 6 'in-crop' irrigations, whereas Riverina crops may need 10 or 11 irrigations, depending on the soil's water-holding capacity and the variety.<sup>26</sup>

**Nutrition**

Acceptable yields of grain or silage require high levels of soil fertility. Both require the main essential nutrients (N, P and K) (Figure 26), although a silage crop removes more of these nutrients, especially K, 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 essential for maize growth. Zinc deficiencies can commonly occur in maize grown on heavy clay alkaline soils. See NSW DPI [Summer crop production guide](#) for more information.

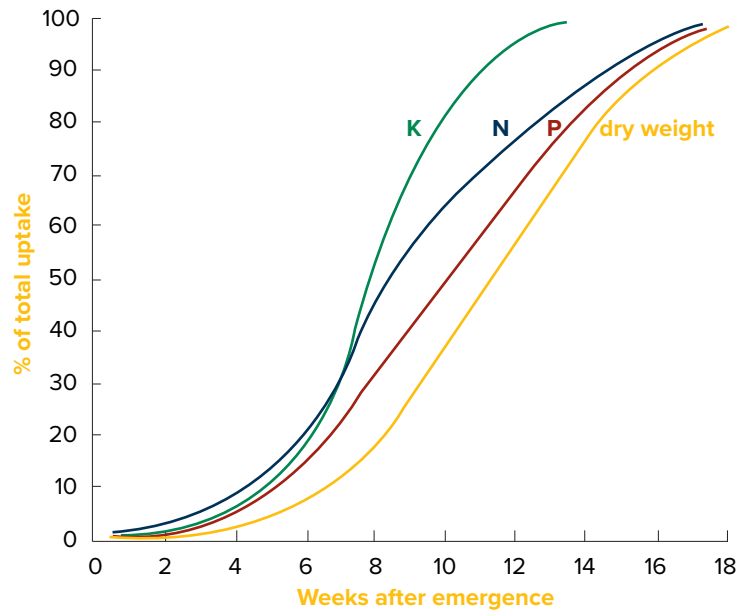
The young plant takes up small amounts of nutrients, but with growth, the nutrient uptake rapidly increases (Figure 27).

<sup>26</sup> K O'Keeffe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)

SECTION 4 MAIZE

TABLE OF CONTENTS

FEEDBACK



**Figure 26:** Uptake of nitrogen (N), phosphate (P), and potassium (K), and dry weight accumulation.

Source: Colless 1992

Maize development	Weekly requirements (as percentage of total need)			
	% 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
<b>Silking</b>	12	15	8	12
<b>Tasseling</b>	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
<b>Emergence</b>	less than 1	less than 1	less than 1	less than 1

**Figure 27:** Requirements of major nutrients and water.

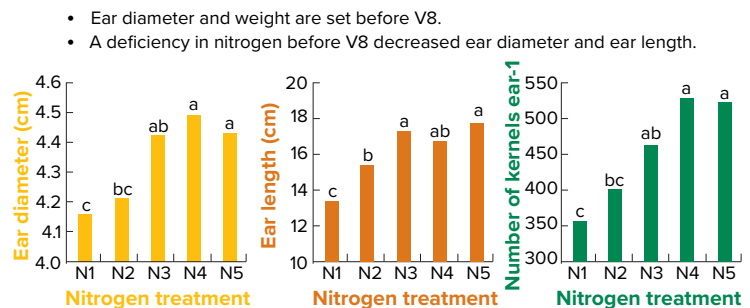
Source: Colless 1992



### Nitrogen

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

Figure 28 shows the effects of different N treatments on ear diameter, ear length, and number of kernels per ear. Early-season stress can influence ear development. A deficiency in N before V8 (treatment N1 in Figure 28) caused an irreversible decrease in ear diameter and ear length, as well as number of kernels per ear. From treatment N1, we see that if N is not applied until after V8, there is a significant yield reduction; even though N was supplied for the rest of the season, this did not help increase the yield, because the ear parameters had been set earlier.



**Figure 28:** Effects of different nitrogen treatments on ear diameter, ear length, and number of kernels per ear. N1, Withholding N supply from seedling to V8; N<sub>2</sub>, withholding N supply after V8; N<sub>3</sub>, withholding N supply after silking; N<sub>4</sub>, withholding N supply from 3 weeks after silking to physiological maturity; N<sub>5</sub>, continuous N supply from emergence to physiological maturity (control). Columns with the same letter within each parameter are not significantly different from one another at P=0.05.

Source: Subedi and Ma 2005

The rate of nutrient uptake (Figure 29) in the plant is similar to that of dry matter accumulation (refer to Figures 26 and 15). 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 stages must be high.

### Phosphorus

A large proportion of the N and P taken up by the plant is removed in the grain at harvest (Figure 29).

### Potassium

By the end of flowering, the plant has taken up >90% of its K requirement (Figure 29). The plant continues to take up N until about 2 weeks after flowering, and it keeps taking up P for 4 weeks after flowering. Uptake of K is completed soon after silking (Figure 29). Most of the K taken up is returned to the soil in the leaves, stalks and other plant residues. Repeated removal of plant material through hay-making or silage can lead to K deficiency in the soil.<sup>27</sup>

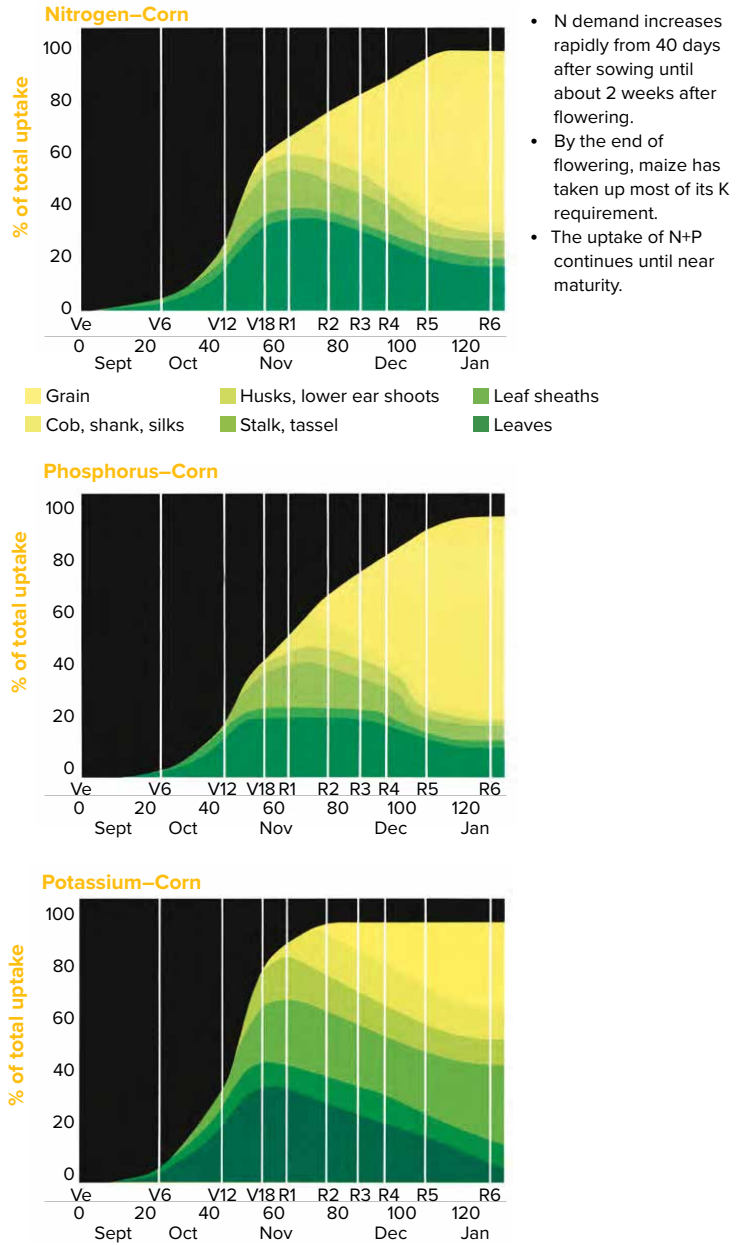
27 K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)



SECTION 4 MAIZE

TABLE OF CONTENTS

FEEDBACK



**Figure 29:** 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

## 4.3 Reproductive development

### 4.3.1 Stages

#### Tasselling–VT

The tassel (Figure 30) is the male flowering structure of the maize plant. Figure 31 shows tassel development from VT to pollen shed.

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 2–5 million pollen grains. If there are 1000 silks per cob, there are 2000–5000 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 many florets on each plant. A large volume of pollen ensures enough pollen for every exposed silk.

Normally, the tip of the tassel can be seen at about the time that the tip of the emerging ear becomes visible. The tassel emerges from the enclosing leaves before pollen shed (Figure 30), which is usually 1–2 days before silks first appear.<sup>28</sup>



**Figure 30:** Plant at the VT stage with the tassel fully developed.

Source: Ritchie et al. 1992

<sup>28</sup> K O'Keefe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)



**Figure 31:** Tassel growth and development from VT through to pollen shed.

Source: Ritchie et al. 1992

### Flowering (pollen shed and silking)–R1

There are two parts to the pollination process:

1. Viable pollen must be shed and land on receptive silks.
2. The pollen must germinate and form pollen tubes to allow male gametes (sex cells) to fuse with female gametes inside the ovule.

#### *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. At least 100 pollen grains/cm<sup>2</sup>.day are needed to successfully pollinate a maize field.

Pollen grains are light and can be carried on the wind, but most settle within 5–15 m from 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 5–10 days), with peak production on about the third day. Pollen shed begins from the middle of the central spike of the tassel 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, midsummer day, peak shedding occurs between 9am and 11am (EST).

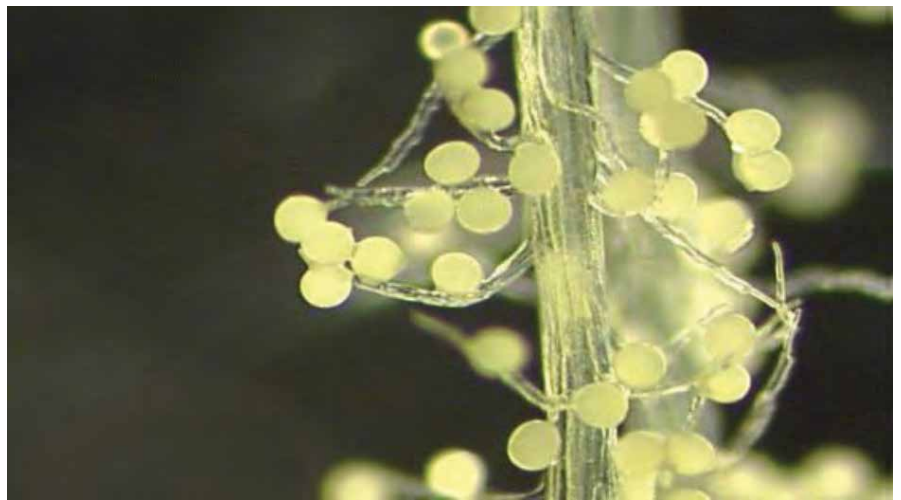
Despite the overlap in timing of pollen shed and silking, pollen of a given plant rarely lands on the silks of the same plant. This is due to air movement, leaf placement and the vertical separation between the tassel and the ear. Under normal field conditions, up to 97% of the kernels produced by a 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 1–3 days after pollen shed has begun. Under favourable growing conditions, all silks will emerge and be ready for pollination within 3–5 days, which is enough time for all silks to receive pollen before the tassel stops shedding pollen.

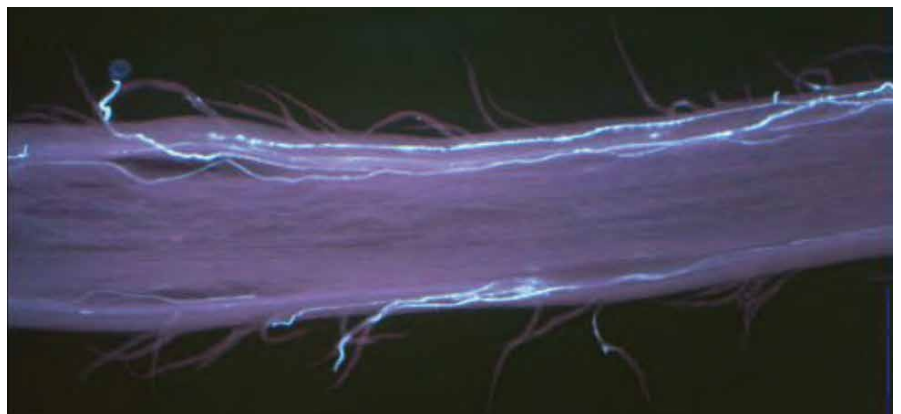
As is the case with other plant parts, silk growth takes place mostly at night; studies have shown that silks can grow 5–8 cm in a single night. The silks from near the base of the ear emerge first, after growing for several days, and those from the tip appear last. Silks generally appear outside the 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 32 and 33).



**Figure 32:** *Pollen sticking to the trichomes on the silks.*

Source: Strachan 2001



**Figure 33:** *Trichomes extending from the main stem of the silk.*

Source: Strachan 2001

### *Fertilisation and growth of the pollen tubes*

Pollen grains contain starch as an energy supply, and they germinate within a few minutes of landing on the trichomes. They produce a pollen tube, which grows down the silk channel and enters the ovary (Figure 34). These pollen tubes always grow near the silk. This is because the silks supply all of the necessary nutrients and water for growth of the pollen tubes.



The pollen tube grows the length of the silk in 12–28 h. 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 from just a few hours to ~1 day for pollen tubes to grow all 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.<sup>29</sup>



**Figure 34:** *Pollen tubes growing along silk vascular tissue.*

Photo: Antonio Perdomo, Pioneer Hi-Bred

### 4.3.2 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. In other words, pollination functions as an ‘on–off’ switch for eventual grain yield.

Although the pollination process may seem vulnerable to weather problems, some features help to make it work. Pollen does not shed when the humidity is high, so generally, it is not 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 10–14 days before and after flowering.

<sup>29</sup> K O’Keeffe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)



SECTION 4 MAIZE

TABLE OF CONTENTS

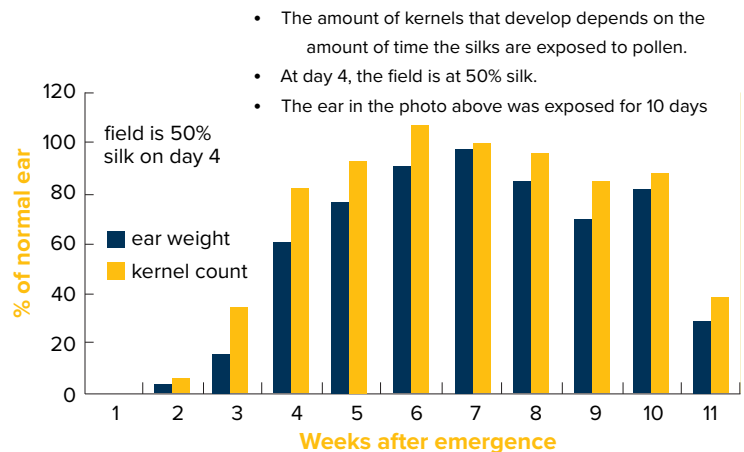
FEEDBACK

The amount of water available for silk growth substantially influences when silks emerge, their rate of growth, the duration of the 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 (Figure 35). In Figure 35, the developing ears were exposed to pollen for 1 day then covered to exclude pollen again; the ear on the left was exposed for the 10 days of pollen shed. Portions of the cobs are barren because mature ovules were not properly fertilised. These unfertilised ovules begin to disintegrate and disappear before the ear reaches physiological maturity.

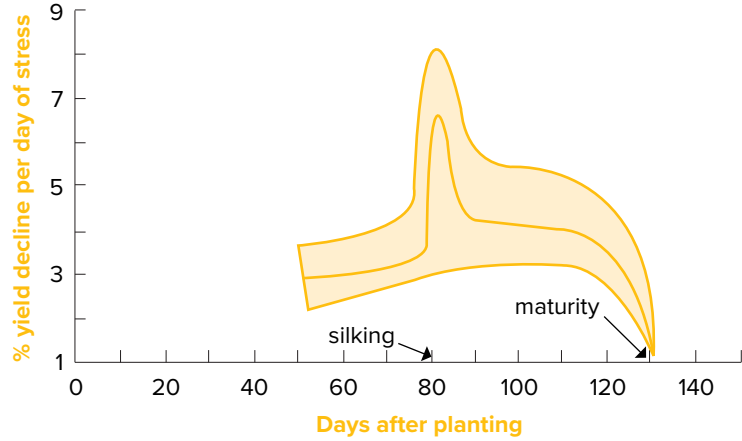
Moisture stress at flowering or during grainfill reduces the number of kernels per plant and, in turn, grain yield. Grain yield is reduced 2–3-fold more when moisture stress coincides with flowering than at other growth stages (Figure 36).

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



**Figure 35:** The proportion of kernels that develop depends on the amount of time that silks are exposed to pollen.

Source: Strachan 2001



**Figure 36:** Relationship between age of crop and percentage yield decrease due to 1 day of moisture stress.

Source: Shaw 1976

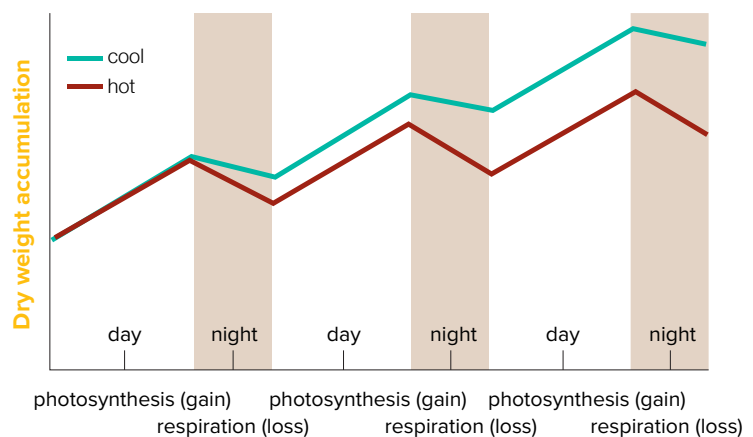
### Temperature

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

The ideal daytime temperature is 26°–30°C, but with full irrigation, maize can tolerate high temperatures.

When temperatures reach  $\geq 38^\circ\text{C}$ , it is difficult to maintain adequate water movement through the plant, even under irrigation.

Night-time temperatures  $>21^\circ\text{C}$  can result in wasteful respiration and lower dry matter accumulation in the plant (Figure 37).



**Figure 37:** Plant growth involves accumulation of dry weight from photosynthesis during the day and loss of respiration at night. When night-time temperatures are too high, respiration loss is excessive (lower line). The result is similar on a very cloudy, warm day.

Source: Hoefl et al. 2000



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

**Table 3:** *Effect of night-time temperature on grain yield.*

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

### Pollination

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

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

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 shed properly and complete the fertilisation process. However, if the water supply is inadequate, pollen will die prematurely and not complete fertilisation.

### 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 critical period too. 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 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.<sup>30</sup>

<sup>30</sup> K O'Keeffe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)

## 4.4 Kernel development

### 4.4.1 Stages

#### 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.

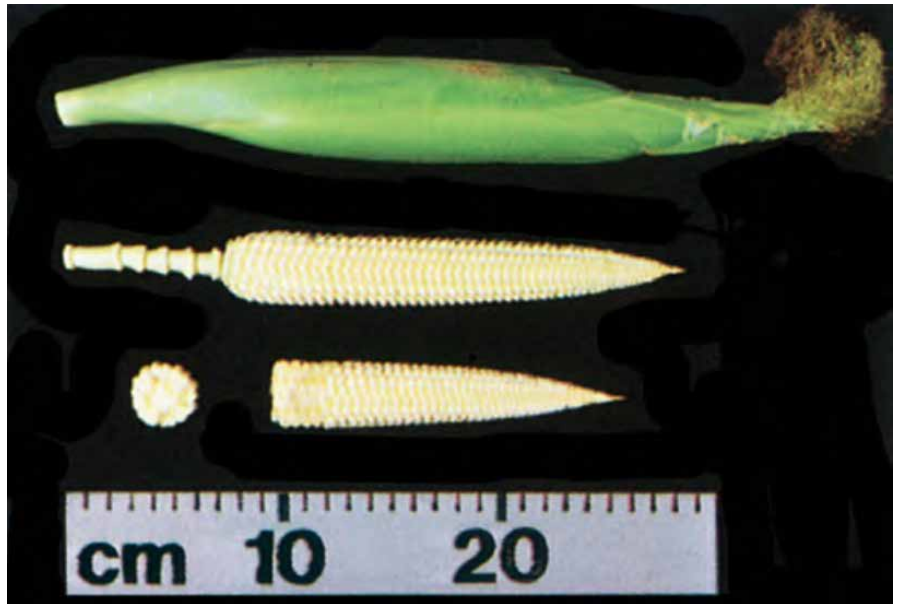
Ten days after fertilisation, developing kernels (Figure 38) appear as watery blisters on the cob; this is the blister stage or R2 (Figure 39). By this time, the cob has reached its full length and diameter.

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



**Figure 38:** *Kernel attachment to the cob.*

Source: Strachan 2001



**Figure 39:** *The R2 (blister) stage.*

Source: Ritchie et al. 1992

### R3 (milk stage)

Around 20 days after pollination, the kernels are yellow on the outside and 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 40). 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.



**Figure 40:** *The R3 (milk) stage.*

Source: Ritchie et al. 1992

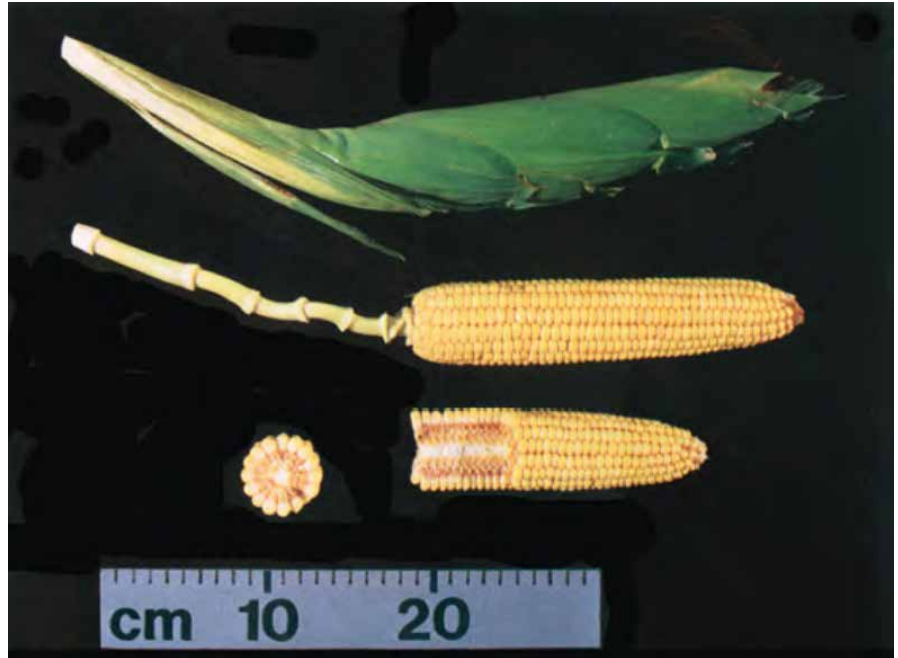
### R4 (dough stage)

From the beginning of the dough stage (3 weeks after silking) (Figure 41) 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 the 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.



**Figure 41:** *The R4 (dough) stage.*

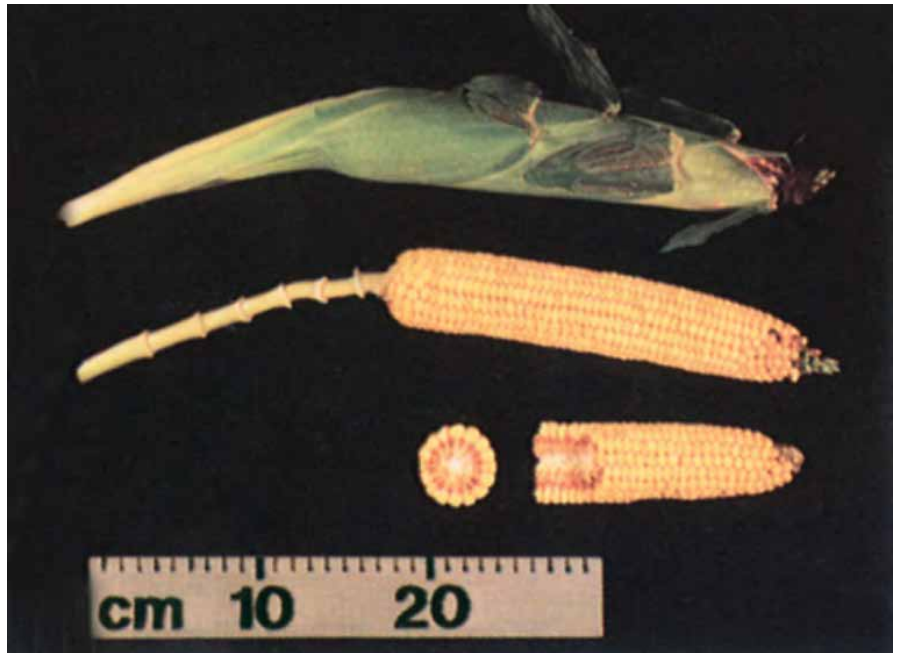
Source: Ritchie et al. 1992

### 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 42), a definite band can be seen across the kernel. The band, also referred to as the milk line (Figure 43), is the line between the milky deposits and the maturing dry starch.

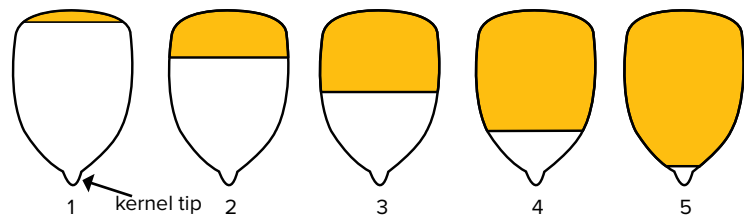
The amount of dry matter in the kernel is increasing. In the soft dough stage, about 55% of the kernels are starting to dent, and in the hard dough stage >90% are dented. By the end of the seventh week of kernel development, the embryo has nearly reached its full size, filling has begun to slow, and the kernel is approaching maturity.<sup>31</sup>

<sup>31</sup> K O'Keeffe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)



**Figure 42:** *The R5 (dent) stage.*

Source: Ritchie et al. 1992



**Figure 43:** *The receding milk line.*

Source: Colless 1992

#### 4.4.2 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. This tissue 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 44). 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 50–60 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.



**Figure 44:** *The R6 stage (physiological maturity).*

Source: Ritchie et al. 1992

### Factors affecting kernel development

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

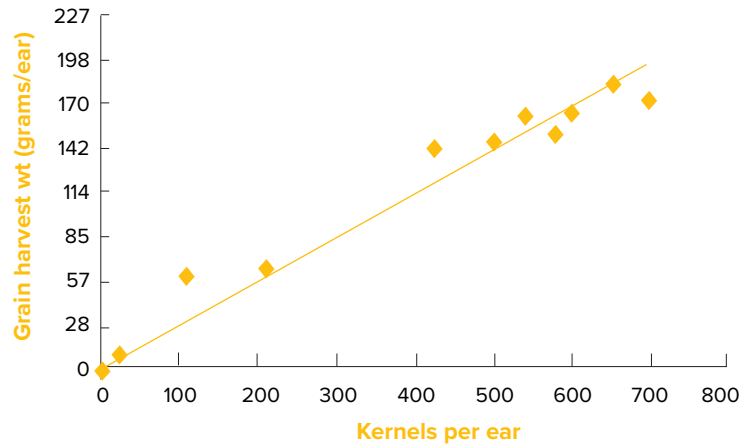
Conditions during kernel development determine kernel size, whereas conditions in earlier growth stages mainly determine the number of ears and kernels per ear (Figure 45).

Understanding stress during kernel filling can help explain why cobs have aborted kernels or abnormal fill patterns (Figures 46 and 47).

SECTION 4 MAIZE

TABLE OF CONTENTS

FEEDBACK



**Figure 45:** Grain yield per ear as a function of number of kernels per ear from the experiment in Figure 35.

Source: Strachan 2001



**Figure 46:** Environmental stress has reduced the width and length of the cob on the right.

Photo: Kieran O'Keefe



**Figure 47:** Various stress factors can lead to missing kernels.

Source: Strachan 2001

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

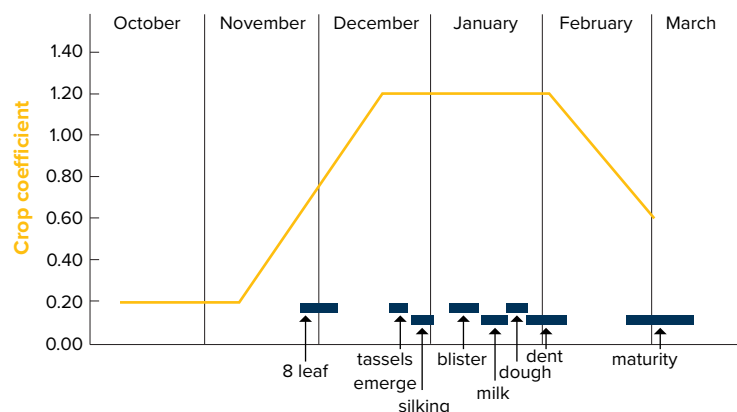
In cases of extreme stress, the plant dies before the grain has reached full size. On the other hand, exceptionally favourable moisture conditions can result in better than expected kernel fill and give a higher grain yield.

When maize plants become moisture-stressed, the lower parts of the plant wilt and suffer proportionately more damage 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 forming on the cobs. It is therefore important to select early-maturing hybrids in dryland or limited-irrigation situations.

Figure 48 is an example of the estimated daily water use. The tasselling–dough period is the time of peak water use and, therefore, very susceptible to moisture stress. Within this period, the silking–blister stage is critical. Consequently, if only one watering can be given, it should be applied just before tasselling.

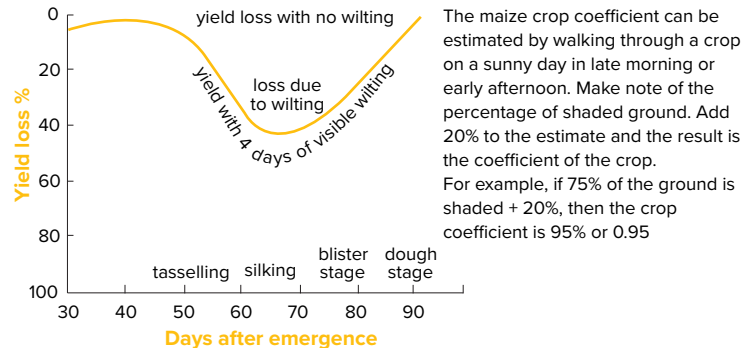
Yield is generally lost when maize is visibly wilted for 4 consecutive days. Figure 49 shows the yield loss due to wilting at various stages.



**Figure 48:** 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





**Figure 49:** Yield loss due to wilting.

Source: Colless 1992

#### 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 43) so there is ample soil moisture for the crop to completely fill the grain. If the crop suffers moisture stress during the last 10–14 days before maturity, yield is reduced by <1% per day, but this is still a significant loss if the stress persists for a number of days.<sup>32</sup>

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<sup>32</sup> K O’Keeffe (2009) Maize growth & development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0007/516184/Procrop-maize-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf)

SECTION 4 MAIZE

TABLE OF CONTENTS

FEEDBACK

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# Nutrition and fertiliser

## 5.1 Declining soil fertility

The natural fertility of cropped agricultural soils is declining over time, and so growers must continually review their management programs to ensure the long-term sustainability of high quality grain production. Paddock records, including yield and protein levels, fertiliser test strips, crop monitoring, and soil and plant tissue tests all assist in the formulation of an efficient nutrition program.

Pasture leys, legume rotations and fertilisers all play an important role in maintaining and improving the chemical, biological and physical fertility of soils, fertilisers remain the major source of nutrients to replace those removed by grain production. Fertiliser programs must supply a balance of the required nutrients in amounts needed to achieve a crop's yield potential. The higher yielding the crop, the greater the amount of nutrient removed. Increasing fertiliser costs means growers are increasing pulses within their crop rotation and even the use of ley pastures to complement their fertiliser programs and possibly boost soil organic matter.<sup>1</sup>

### 5.1.1 Soil organic matter

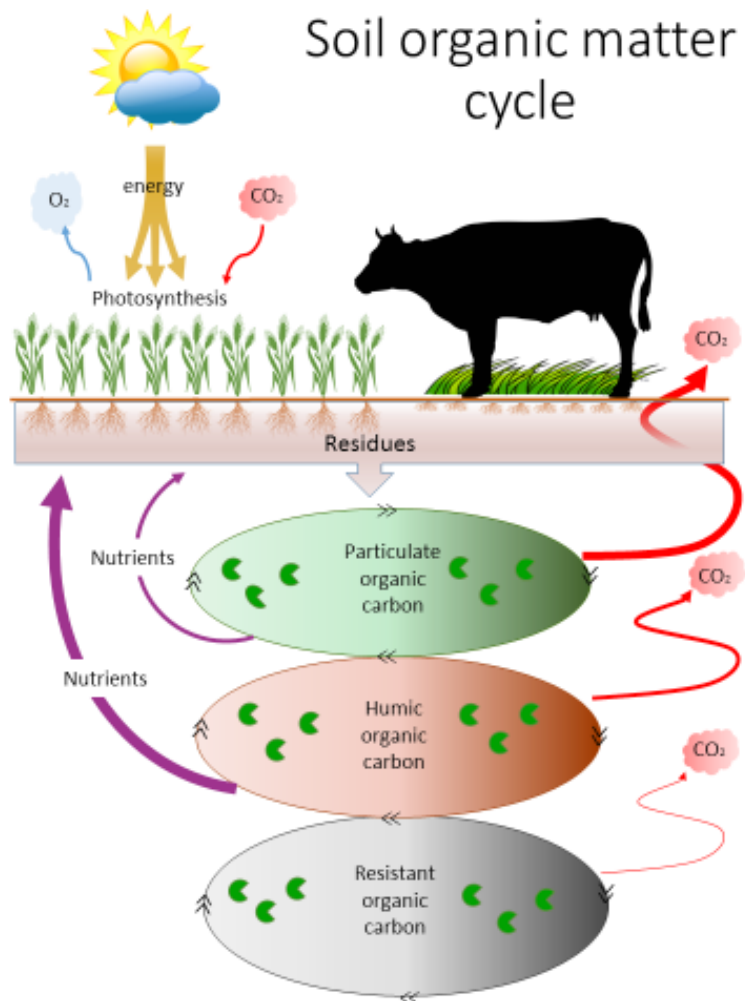
Soil organic matter (SOM) is a critical component of healthy soils and sustainable agricultural production. Growers understand that crops grown in healthy soils perform better and are easier to manage. Soil organic matter is '*all of the organic materials found in soils irrespective of its origin or state of decomposition*'<sup>2</sup> that is anything in or on the soil of biological origin, alive or dead. It is composed mainly of carbon (approximately 60%) as well as a variety of nutrients (including nitrogen, phosphorus and sulfur). It is difficult to actually measure the SOM content of soil directly so we measure the soil organic carbon (SOC) content and estimate SOM through a conversion factor:

Soil organic matter (%) = organic carbon (%) × 1.72

It is important to understand the role of plants in the SOM cycle. Photosynthesis is the process by which plants take in carbon dioxide (CO<sub>2</sub>) from the atmosphere, combine with water taken up from the soil, and utilising the energy from the sun, form carbohydrate (organic matter) and release oxygen (O<sub>2</sub>). This is the start of the SOM cycle. When the leaves and roots (carbohydrate) die they enter the soil and become SOM. These residues are decomposed by soil organisms which provides them with the energy to grow and reproduce. The SOM cycle is a continuum of different forms (or fractions) with different time frames under which decomposition takes place. Over time SOM moves through these fractions; particulate, humic and resistant fractions. As SOM decomposes carbon is released from the system along with any nutrients that are not utilised by the microorganisms. These nutrients are then available for plants to utilise. Eventually a component of these residues will become resistant to further decomposition (resistant fraction Figure 1).

<sup>1</sup> QDAF (2010) Nutrition management. Overview. Department of Agriculture, Fisheries and Forestry Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview>

<sup>2</sup> JA Baldock, JO Skjemstad (1999) Soil organic carbon/Soil organic matter. In KI Peverill, LA Sparrow, DJ Reuter (eds). Soil analysis: An interpretation manual. CSIRO Publishing, Collingwood Australia.



**Figure 1: Organic matter cycle.**

Source: J Gentry, QDAF

Organic matter is fundamental to several of the physical, chemical and biological functions of the soil. It helps to ameliorate or buffer the harmful effects of plant pathogens and chemical toxicities. It enhances surface and deeper soil structure, with positive effects on infiltration and exchange of water and gases, and for keeping the soil in place. It improves soil water-holding capacity and, through its high cation-exchange capacity, prevents the leaching of essential cations such as calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na). Most importantly, it is a major repository for the cycling of nitrogen and other nutrients and their delivery to crops and pastures.

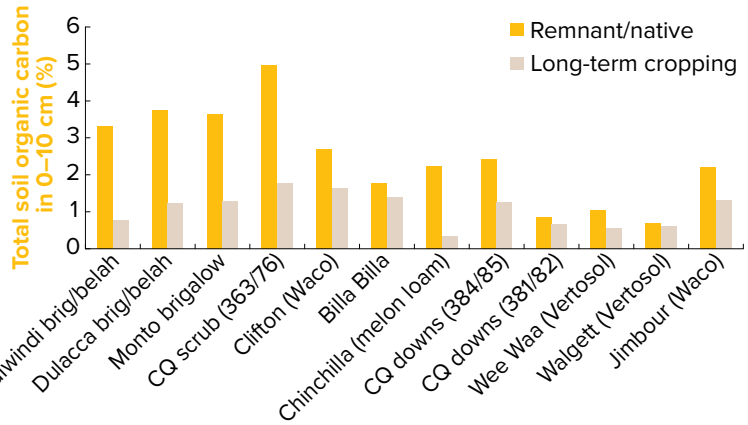
Australian soils are generally low in SOM. Initial SOM levels are limited by dry matter production (and so climate) for each land type/location. SOM levels have declined under traditional cropping practices. On-farm measures (sampled 2012–15) from over 500 sites in Queensland and northern NSW confirm that soil organic matter, measured as soil organic carbon, declines dramatically when land is cleared and continuously cropped. This decline affects all soils and land types but is most dramatic for the brigalow–belah soils because their starting organic carbon levels are so high (Figure 2).<sup>3</sup>

<sup>3</sup> QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, <http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANSTrials2015-screen.pdf>

SECTION 5 MAIZE

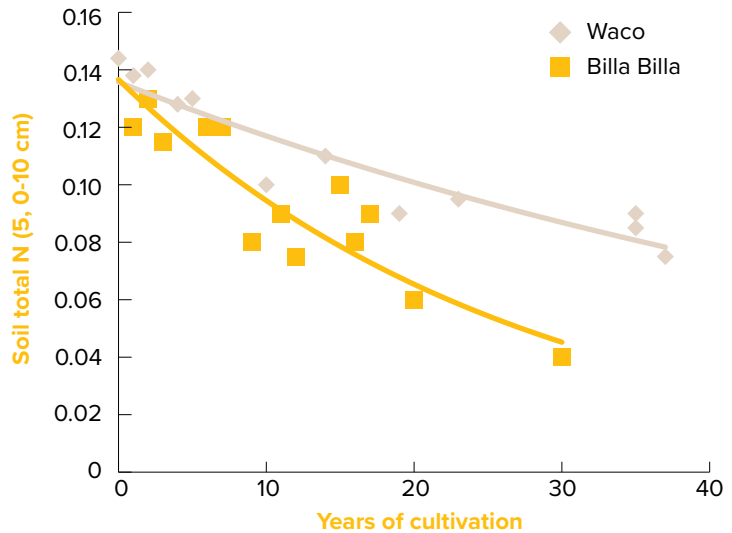
TABLE OF CONTENTS

FEEDBACK



**Figure 2:** The decline of soil organic carbon in long-term cropping systems. <sup>4</sup>

Declining levels of SOM have implications for soil structure, soil moisture retention, nutrient delivery and microbial activity. However, probably the single most important effect is the decline in the soil’s capacity to mineralise organic nitrogen (N) to plant-available N. Past research (1983) has shown that N mineralisation capacity was reduced by 39–57%, with an overall average decline of 52% (Figure 3). <sup>5</sup> This translated into reduced wheat yields when crops were grown without fertiliser N.



**Figure 3:** Graph of decline in soil total N with years of cropping. The decline was greater for the Billa Billa soil (clay content 34%) than the Waco soil (clay content 74%). <sup>6</sup>

Source: based on Dalal & Mayer (1986a,b)

<sup>4</sup> QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, <http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf>  
<sup>5</sup> RC Dalal, RJ Mayer (1986) Long term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. II. Total organic carbon and its rate of loss from the soil profile. Australian Journal of Soil Research 24, 281–292.  
<sup>6</sup> RC Dalal, RJ Mayer (1986) Long term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. II. Total organic carbon and its rate of loss from the soil profile. Australian Journal of Soil Research 24, 281–292.

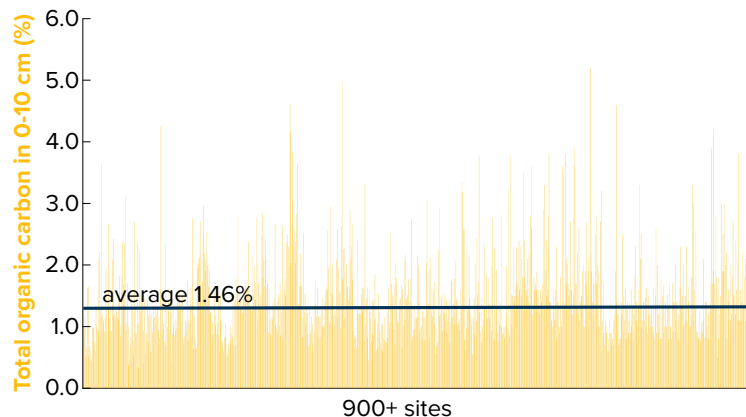


### 5.1.2 Current situation

Soil organic carbon levels are simply a snapshot of the current balance between inputs (e.g. plant residues and other organic inputs) and losses (e.g. erosion, decomposition) constantly happening in each soil and farming system. The decline over time is overwhelmingly driven by the extent of fallowing in our farming systems. Most fallow rain in the northern region (as much as 75–80% in a summer fallow) is lost as runoff or evaporation. This wasted rain does not grow dry matter to replenish the organic matter reserves in the soil. However, increasing moisture in the fallowed soil continues to support microbial decomposition. This helps accumulate available nitrogen for the next crop, but reduces soil organic carbon. The soil organic matter and carbon levels will continue to decline until they reach a new lower level that the dry matter produced by the new farming system can sustain. Put simply,

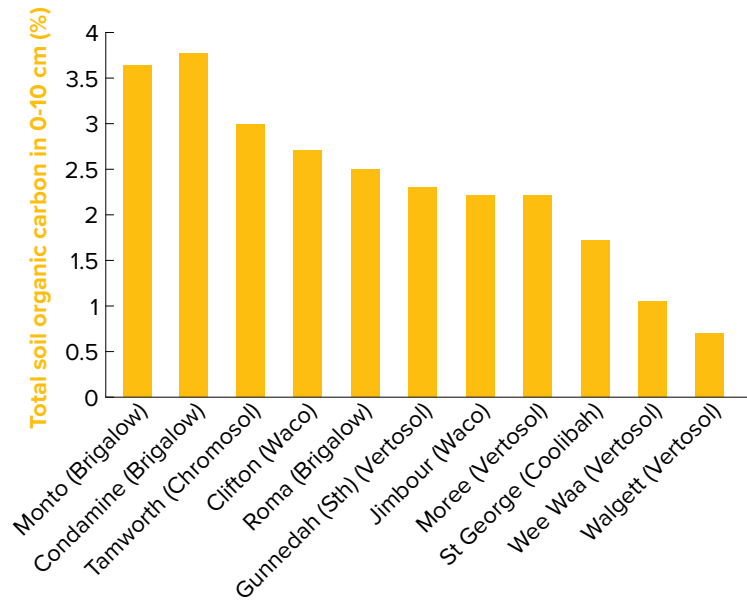
*‘Crops may make more money than trees and pastures, but do not return as much dry matter to the soil.’*

Total soil organic carbon levels vary within a paddock, from paddock to paddock and from region to region. Comprehensive sampling was undertaken throughout the northern region, with over 900 sites sampled and analysed for total organic carbon at 0–10 cm depth. These results varied enormously across sites. The average was 1.46% however it varied from under 0.5% to over 5% (Figure 4).<sup>7</sup> A selection of these data from representative soil types throughout the northern grains region clearly indicates how soil carbon levels can be significantly different due to soil type (Figure 5).<sup>8</sup>



**Figure 4:** Soil organic carbon levels on mixed farms within the GRDC Northern Region.<sup>9</sup>

7 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112 – 117, <http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf>  
 8 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, <http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf>  
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**Figure 5:** Impact of land-type on total soil carbon levels (0–10 cm) across the northern region.<sup>10</sup>

### 5.1.3 Options for reversing the decline in soil organic matter

Soil organic matter is an under-valued capital resource that needs informed management. Levels of SOC are the result of the balance between inputs (e.g. plant residues and other organic inputs) and losses (e.g. erosion, decomposition, harvested material) in each soil and farming.<sup>11</sup> So maximising total dry matter production will encourage higher SOC levels, and clearing native vegetation for grain cropping will typically reduce SOC and SOM levels.<sup>12</sup>

Modern farming practices that maximise Water Use Efficiency for extra dry matter production are integral in protecting SOM. Greater cropping frequency, crops with higher yields and associated higher stubble loads, pasture rotations and avoiding burning or baling will all help growers in the northern region to maintain SOM.

Research in the past has shown the most direct, effective means of increasing SOM levels is through the use of pastures, however these pasture have to be productive. A grass only pasture will run out of N especially in older paddocks, which is normally the reason why these paddocks are retired from cropping. As a result, a source of nitrogen is required to maximise dry matter production, this can be supplied via a legume or N fertiliser. The rotation experiments of I. Holford and colleagues at Tamworth, NSW and R. Dalal and colleagues in southeast Queensland provide good evidence of this (Table 1).

The greatest gains in soil carbon and nitrogen, relative to the wheat monoculture, were made in the 4-year grass–legume ley, with increases of 550 kg total N/ha and 4.2 t organic C/ha. The chickpea–wheat rotation fared no better than the continuous wheat system. The shorter (1–2-year) lucerne and annual medic leys resulted in marginal increases in soil organic C and N (Table 1).

<sup>10</sup> QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, <http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf>

<sup>11</sup> FC Hoyle, JA Baldock, DV Murphy (2011) Soil organic carbon: Role in rainfed farming systems. In PG Tow, I Cooper, I Partridge, C Birch (eds). Rainfed farming systems. Springer, pp. 339–361.

<sup>12</sup> RC Dalal, RJ Mayer (1986) Long term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. II. Total organic carbon and its rate of loss from the soil profile. Australian Journal of Soil Research 24, 281–292.

Clearly, time and good sources of both carbon and nitrogen are required to build up SOM, which is exactly what the 4-year grass–legume ley provided. Nitrogen was supplied via  $N_2$  fixation by the lucerne and annual medic in the pasture, with most of the carbon supplied by the grasses, purple pigeon grass and Rhodes grass. There were no inputs of fertiliser nitrogen in any of the treatments in Table 1.<sup>13</sup>

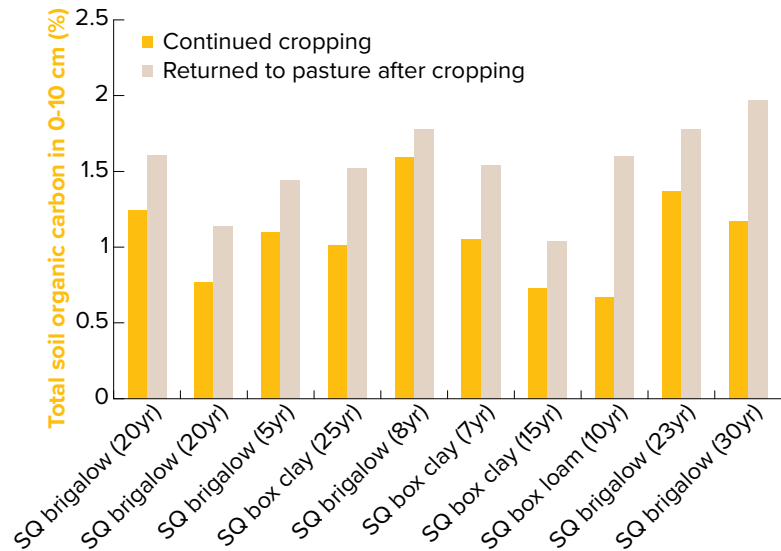
**Table 1:** Effects of different rotations on soil total N and organic C (t/ha) to 30 cm and as gain relative to continuous wheat.

Rotation	Wheat crops	Soil total N		Organic C	
		0–30 cm	Gain	0–30 cm	Gain
Grass/legume ley 4 years	0	2.91	0.55	26.5	4.2
Lucerne ley (1-2 years)	2-3	2.56	0.20	23.5	1.2
Annual medic ley (1-2 years)	2-3	2.49	0.13	23.1	0.8
Chickpeas (2 years)	2	2.35	0.00	22.0	0.0
Continuous wheat 4 years	4	2.36	-	22.3	-

Further research was initiated in 2012 to identify cropping practices that have the potential to increase or maintain soil organic carbon and soil organic matter levels at the highest levels possible in a productive cropping system. Paired sampling has shown that returning cropping country to pasture will increase soil carbon levels (Figure 6). However, there were large variations in carbon level increases detected, indicating not all soil types or pastures perform the same. Soil type influences the speed by which carbon levels change, i.e. a sandy soil will lose and store carbon faster than a soil high in clay. As too does the quality and productivity of the pasture, maximising dry matter production by ensuring adequate nutrition (especially in terms of nitrogen and phosphorus) will maximise increases in soil carbon over time. Current research in Queensland being undertaken by the Department of Agriculture, Fisheries and Forestry (QDAF) is indicating that the most promising practice to date to rebuild soil carbon stocks, in the shortest time frame, is the establishment of a highly productive pasture rotation with annual applications of nitrogen fertiliser, however, adding an adapted legume is also effective.<sup>14</sup>

<sup>13</sup> D Herridge (2011) Managing legume and fertiliser N for northern grains cropping. Revised 2013. GRDC, <https://grdc.com.au/uploads/documents/Managing-N-for-Northern-Grains-Cropping.pdf>

<sup>14</sup> QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, <http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf>



**Figure 6:** Total organic carbon comparisons for croplands resown to pasture. <sup>15</sup>

### Impact of fertiliser N inputs on soil

If the rates of fertiliser N are sufficiently high, the effects can be positive. In the Warra experiments, both soil organic C and total N increased marginally (3–4%) over an 8-year period when no-till, continuous wheat, fertilised at a rate of 75 kg N/ha, was grown. This is in contrast with decreases of 10–12% in soil organic C and N in the non-fertilised, continuous wheat and chickpea–wheat plots. The result was much the same in NSW Department of Primary Industries experiments in northern NSW. At the Warialda site, for example, SOM increased during 5 years of cropping but only where fertiliser N had been applied to the cereals.

It is clear from the above examples that building SOM requires N. It works in two ways. First, the fertiliser or legume N produces higher crop/pasture yields and creates more residues that are returned to the soil. Then, these residues are decomposed by the soil microbes, with some eventually becoming stable organic matter or humus. The humus has a C/N ratio of about 10:1, i.e. 10 atoms of C to 1 atom of N. If there are good amounts of mineral N in the soil where the residues are decomposing, the C is efficiently locked into microbial biomass and then into humus.

If, on the other hand, the soil is deficient in mineral N, then more of the C is respired by the soil microbes and less is locked into the stable organic matter. <sup>16</sup>

## 5.2 Nutrition

Maize yield and quality are both affected by crop nutrition. Maize is responsive to fertiliser, especially nitrogen (N), phosphorus (P) and potassium (K). High-yielding maize crops require large quantities of soil nutrients. In a healthy maize crop, all of the upper leaves and most of the lower leaves remain green until the crop is nearly mature (Figure 7). To ensure optimal use of fertilisers, a soil test should be conducted prior to planting.

Maize grows best in soils with a pH range of 5.6–7.5. If the pH is <5, lime should be applied and incorporated into the soil 3–6 months before planting. An alternative is to

<sup>15</sup> QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, <http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf>

<sup>16</sup> D Herridge (2011) Managing legume and fertiliser N for northern grains cropping. Revised 2013. GRDC, <https://grdc.com.au/uploads/documents/Managing-N-for-Northern-Grains-Cropping.pdf>

**i MORE INFORMATION**

R Lines-Kelly (2004) Which liming material is better? NSW DPI.

G MacKinnon et al. Soil fertility management in low-rainfall farming systems of central western NSW. NSW DPI.

Making Better Fertiliser Decisions for Cropping Systems in Australia.

**i MORE INFORMATION**

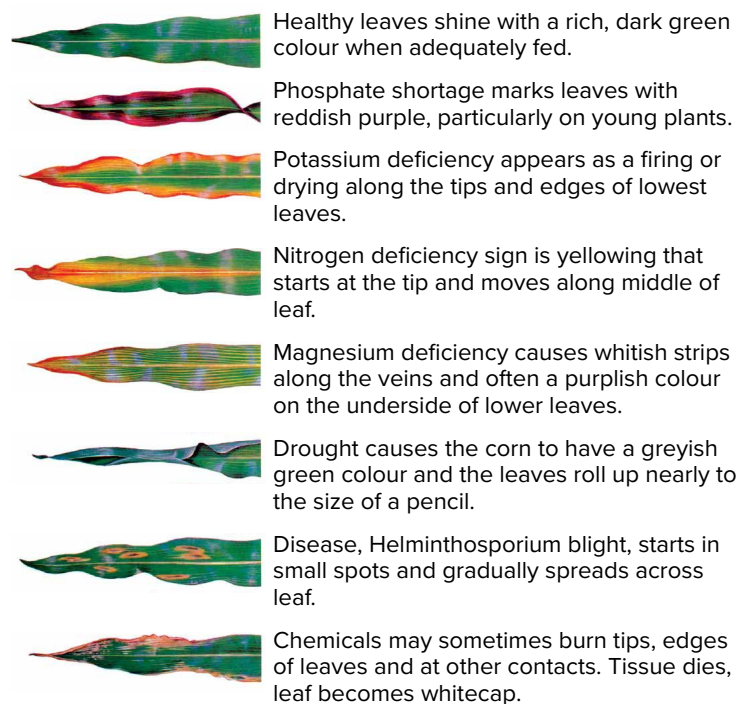
Saline, sodic, magnesic or all of the above? Back Paddock Company.



apply dolomite, which has a neutralising value similar to lime but applies magnesium (Mg), which may cause cation imbalance if used incorrectly.<sup>17</sup> Consult your agronomist or soil nutrition expert to get recommendations for your situation.

Of all the essential nutrients derived from the soil, N, P and K (the primary nutrients) represent 83% of the total absorbed. Calcium (Ca), Mg and sulfur (S) are the secondary nutrients and represent another 16%, leaving only 1% as micronutrients.

The amounts of micronutrients—boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn)—required are very small but these are still important to achieving maximum yield and should only be applied when necessary.



**Figure 7:** *In a healthy maize crop, all of the upper leaves and most of the lower leaves remain green until the crop is nearly mature.*

Some soil nutrients are more likely to have deficiency problems than others, for example zinc deficiency on high pH soils. Of the secondary nutrients, Mg and S are the most likely to be a problem, and then usually only on low pH and/or sandy soils, and Mg may even be too high.

Once a yield goal has been set, a fertiliser program can be worked out to provide the necessary nutrients. The yield goal should be set so that it falls in the upper ranges of what is believed attainable, and then the amounts of fertiliser needed to reach that goal should be calculated. Figure 8 shows the amounts of N, P, K, S and Mg removed by a maize crop depending on yield and on whether the crop is for grain alone or for silage. A crop of 5.5 t grain/ha (40 t green chop/ha) is a yield that could be obtained under reasonable dryland conditions. A crop of 11 t of grain/ha (65 t green crop/ha) is achievable under irrigated cropping conditions.

The Australian record for a maize crop is 21.5 t grain/ha and the genetic potential is believed to be ~36 t/ha.

<sup>17</sup> QDAF (2012) Nutrition, irrigation and weeds for maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/nutrition-irrigation>



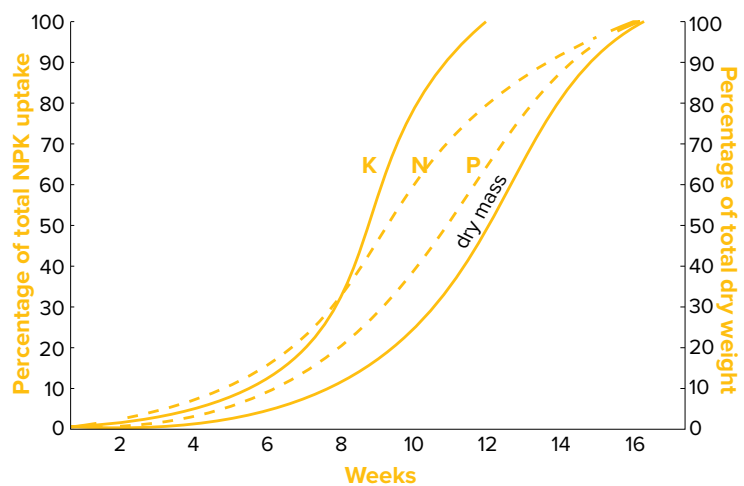
## SECTION 5 MAIZE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

		Kilograms per hectare				
Maize: Grain and silage		N	P	K	S	Mg
5.5 t/ha grain	Grain	121	19	24	9	11
40 t/ha green chop	Stover	44	7	97	11	20
<b>(12.8 t dm/ha)</b>	<b>Total</b>	<b>165</b>	<b>26</b>	<b>121</b>	<b>20</b>	<b>31</b>
7 t/ha grain	Grain	136	24	30	11	13
50 t/ha green chop	Stover	54	10	120	13	25
<b>(16 t dm/ha)</b>	<b>Total</b>	<b>190</b>	<b>34</b>	<b>150</b>	<b>24</b>	<b>38</b>
8.5 t/ha grain	Grain	151	28	36	13	15
58 t/ha green chop	Stover	64	12	143	15	30
<b>(18.5 t dm/ha)</b>	<b>Total</b>	<b>215</b>	<b>40</b>	<b>179</b>	<b>28</b>	<b>45</b>
10 t/ha grain	Grain	176	32	41	15	17
65 t/ha green chop	Stover	74	14	167	17	35
<b>(20.8 t dm/ha)</b>	<b>Total</b>	<b>240</b>	<b>46</b>	<b>208</b>	<b>32</b>	<b>52</b>
11 t/ha grain	Grain	190	35	45	16	18
70 t/ha green chop	Stover	80	15	180	18	35
<b>(22.4 t dm/ha)</b>	<b>Total</b>	<b>270</b>	<b>50</b>	<b>225</b>	<b>34</b>	<b>56</b>

**Figure 8:** Plant nutrients taken up by the maize crop according to yield goals.

Whereas Figure 8 shows the total quantity of major nutrients required, Figure 9 indicates the periods and rates of uptake for N, P and K. By using the two tables in conjunction, the fertiliser quantities required by the maize crop at each stage of growth can be calculated.<sup>18</sup>



**Figure 9:** Timing and rates of uptake for nitrogen, phosphorus and potassium.

Source: Pioneer

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[Summer crop production guide 2014. NSW DPI Management Guide.](#)

[Nutrient sources for crops. Incitec Pivot Fertilisers.](#)

[Growth potential. Corn grower's workshop. Pioneer Hi-Bred Australia.](#)

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<sup>18</sup> Growth potential. Corn grower's workshop. Pioneer Hi-Bred Australia. [http://www.pioneer.com/CMRoot/International/Australia\\_Intl/Publications/Corn\\_Workshop\\_Book.pdf](http://www.pioneer.com/CMRoot/International/Australia_Intl/Publications/Corn_Workshop_Book.pdf)

### 5.3 Soil fertility

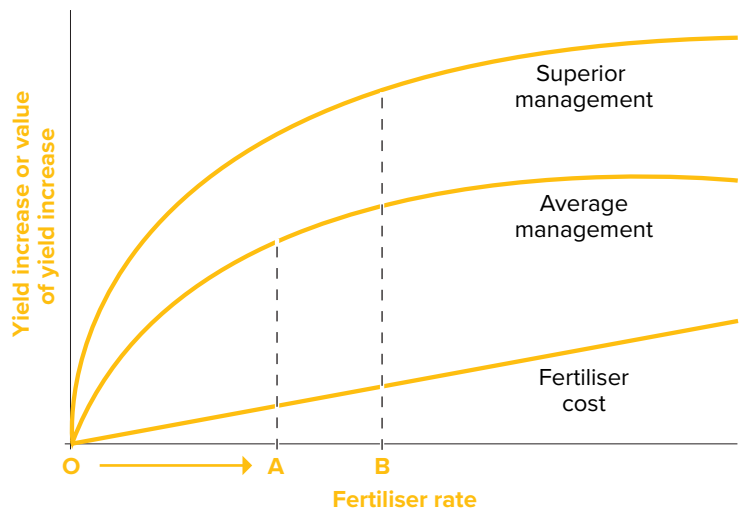
The fertility of a soil is a combination of its physical characteristics (structure, texture, stability, density, organic matter content) and its nutrient status (amount of N, P, K and other essential nutrients that are readily available to the crop). To grow a profitable crop, we should aim for the best combination of physical and chemical characteristics.

The cultural practices employed in growing a crop (e.g. no-till versus conventional farming) will have the greatest effect on a soil's physical structure. The greater the volume of soil the root system can explore, the greater the yield potential.

Growers with hardsetting soils should implement practices such as deep ripping to break hard pans and permanent beds or no-till to improve moisture infiltration to the root-zone of the crop. Inter-row cultivation can also be used to improve crop growth and water infiltration as well as to control weeds.

Apart from some carbon, hydrogen and oxygen derived from the air, the soil is the sole supplier of the plant's nutrient and water requirements (except where foliar fertilisation is used for a specific purpose).

Higher rates of fertiliser can be profitably used with superior management than with average management (Figure 10). In Figure 10, with average management, rate A is optimal, and with superior management, rate B is optimal (from Strizel 1963). The soil holds plant nutrients in many forms. Some are readily available to the plant, whereas others have to be changed from an inorganic to an organic form that the plant can use. Note that although crop nutrient requirements are minimal in the first 6 weeks of growth, the majority of fertiliser should be applied at or prior to planting.



**Figure 10:** Effect of superior management on fertiliser cost returns.

Source: Pioneer

Different types of soil hold different amounts of nutrients and water for the plant to use. Sandy soils are usually low in fertility (low organic matter and leach readily) so will require the fertiliser and water to be applied in such a manner that it is utilised while reducing loss. Some strategies rely on split applications of nutrients through the growing season or the use of foliar fertilisers and need small doses of fertiliser and water often (this is not always practicable).

Clay soils, on the other hand, are inherently more fertile and hold more water because of the higher level of organic matter in the profile and greater cation exchange capacity (a result of their clay mineralogy content). However, tie-up of some nutrients can be an issue.

#### **i** MORE INFORMATION

[Soil phosphorus availability. Incitec Pivot Fertilisers.](#)

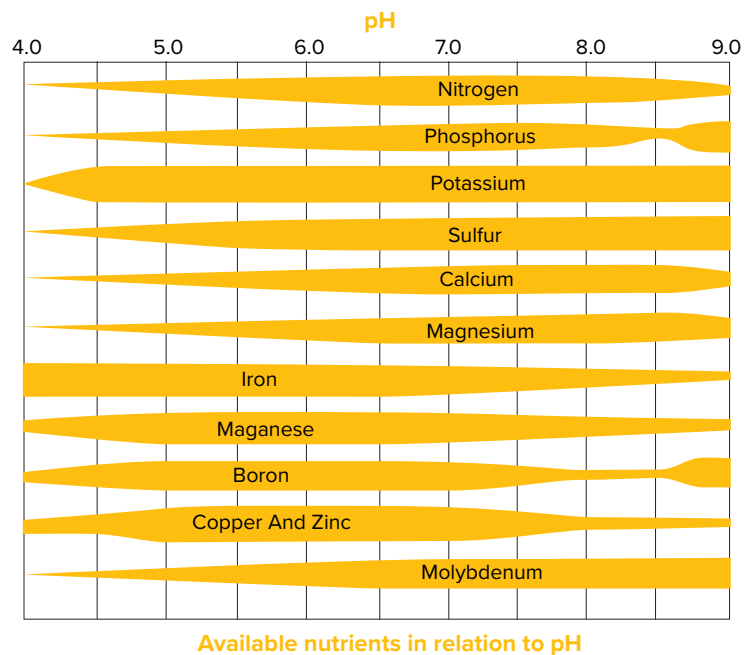
[MJ Bell \*et al.\* \(2008\) Fate of potassium fertilisers applied to clay soils under rainfed grain cropping in south-east Queensland, Australia. \*Australian Journal of Soil Research\* 47.](#)

[G Schwenke \*et al.\* Nitrogen volatilisation losses—how much N is lost when applied in different formulations at different times. NSW DPI.](#)



Not all soils have nutrients in a form available to the plant—some soils have a high fixing capacity (e.g. P in highly calcareous soils or high pH soils).

Another influence on the availability of nutrients is the soil's pH. Figure 11 shows the changes in plant nutrient availability with changes in soil pH. The width of the horizontal bar in Figure 11 indicates the relative availability of each nutrient. Optimum pH for maize is 6.0–7.0. Lime will make soils more alkaline and increase the availability of some nutrients when applied to acid soils.<sup>19</sup>



**Figure 11:** Variability of plant nutrients with soil pH.

Source: Pioneer

**i MORE INFORMATION**

[C Guppy \*et al.\* \(2012\) Interpreting soil tests in the light of P, K and S research. GRDC Update Papers.](#)

[M Bell, C Guppy \(2014\) Interpreting soil test results for the northern region. GRDC Ground Cover Issue 108.](#)

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[The what where and why of soil testing in the northern region](#)

## 5.4 Soil testing

Maize produces a lot of dry matter; therefore, it uses large amounts of nutrients, which many Australian soils are not capable of supplying without the addition of fertilisers. Soils should be regularly tested so that you are aware of the nutrient status, both macro- and micro-nutrients, pH and organic matter.

When you have analysed the soil test results, you can plan a fertiliser program based on available nutrients and, most importantly, your budget or expected yield. If growing maize for silage, a slightly different fertiliser program is needed than for grain.

Growers will need to adjust replacement rates based on removal of both grain and stover. This is a significantly costly fertiliser program.

## 5.5 Key nutrients

Insufficient supply of nutrients leads to deficiency symptoms (Figure 12). Maize takes the large majority of its K by silking but requires a supply of N and P beyond grainfill (Figure 13). The accumulation of water, N, P and K is rapid in the early stages of growth beyond the 4–5-week period.

<sup>19</sup> Growth potential. Corn grower's workshop. Pioneer Hi-Bred Australia. [http://www.pioneer.com/CMRoot/International/Australia\\_Intl/Publications/Corn\\_Workshop\\_Book.pdf](http://www.pioneer.com/CMRoot/International/Australia_Intl/Publications/Corn_Workshop_Book.pdf)

SECTION 5 MAIZE

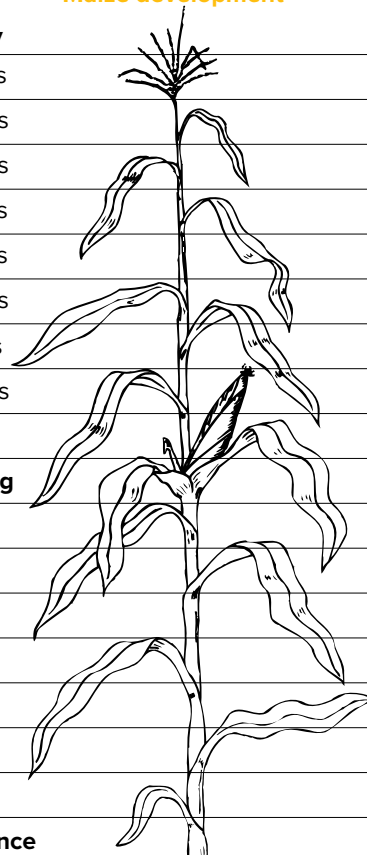
TABLE OF CONTENTS

FEEDBACK



**Figure 12:** *Nutrient deficiency in maize.*

Source: Pacific Seeds

Maturity	Maize development	Weekly requirements (as percentage of total need)			
		% 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
<b>Silking</b>		12	15	8	12
<b>Tasseling</b>		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
<b>Emergence</b>	less than 1	less than 1	less than 1	less than 1	

**Figure 13:** Weekly nutrient requirements of maize.

Source: Incitec Pivot Ltd

Fertiliser application and timing is extremely important, with maize being an aggressive user of nutrients, particularly in the period leading up to tasselling. Nutrients must be available to the plant when most needed.

Because of the high levels of N required, N fertiliser is usually applied pre-planting in the form of urea or anhydrous ammonia or at planting if applying between the rows. Most maize growers split application of N, with ~60–70% applied pre-planting and the remainder applied either water-run or side-dressed prior to tasselling.

The other nutrients are usually applied pre-planting or at planting in the form of starter fertiliser. Only minor rates of K can be applied in the seed trench at sowing; it is better incorporated into soil pre-sowing to provide sufficient rates.

Placement of fertiliser is also important because the emerging maize seedling can tolerate only small amounts of N (5 kg/ha) and P (10 kg/ha) in direct contact. At the same time, emerging seedlings need access to pop-up fertiliser, to give them a good start.

Under cool, wet conditions in soils that are high in pH, uptake of some nutrients can be inhibited and foliar sprays may be required to correct the imbalance. The main nutrients affected are Zn, B, Fe, Mn and Cu (Figure 14).<sup>20</sup>

20 Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09. Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>





**Figure 14:** Severe zinc deficiency in stunted plants.

Source: Pacific Seeds

## 5.6 Animal manure

Manure contains valuable nutrients and organic matter. The composition will vary depending on the animal and the feeding regime. Micronutrient deficiencies are seldom found on fields that regularly receive applications of manure.

The nutrients contained in manure are not as efficient in stimulating plant growth in the short term as chemical fertilisers, but there is a residual effect lasting up to 4 years. This is due to the slow release of the nutrients.

As well as having value in terms of nutrients, manure also acts as a soil improver. Organic matter improves soil structure, helps root penetration and reduces the degree of soil compaction, allowing soils to hold more available water.

Data from a Dalby feedlot showed that the manure contained 2.17% N, 1.28% P and 2.61% K. Therefore, 1 t manure (dry matter) would contain 21.7 kg N; 12.8 kg P and 26.1 kg K. However, only a percentage of this is available in the first year (possibly 35% of the N, 60% of the P and 90% of the K), the rest becoming available in subsequent years. Variations in soil types, climatic conditions and manure used will greatly affect the immediate availability of these nutrients.

Because N is a critical nutrient for producing maximum yields, it is therefore recommended that the amount of N from manure is not calculated in the first growing year of application.



When considering using manure, have an analysis done so that a value can be put on the nutrients it contains. It can be more difficult to put a value on the soil-improving qualities of manure. Each situation must be taken on its own merits but the use of manure has many and lasting benefits.

The theory of maintenance fertilisation has much merit. The soil can be considered a nutrient bank. The healthier it is, the healthier the crop will be and the higher the yields.

The likelihood of a response to fertiliser is reduced by any factor that reduces crop growth. Yield increases from the use of fertilisers depend primarily on:

- the potential yield
- the levels of soil nutrient
- soil moisture at planting
- the ability of the plant to take up nutrients and the availability of plant nutrients and soil moisture throughout the growth of the crop.

Consideration should be given to crop rotations that influence, amongst other factors, the amount of available soil N for succeeding crops. Soil N is more effective for crop growth than is fertiliser N. Nitrogen and K will generally be the most expensive fertiliser inputs in the production of a maize crop.

Just as good management is key to economic crop production, good management is key to economic fertiliser usage.<sup>21</sup>

## 5.7 Crop removal rates

The quantity of N required to grow the crop is about 1.6 times the quantity that will be removed in the grain. Other crop removal rates are listed in Table 2.

**Table 2: Nitrogen, phosphorous and potassium removal (kg/ha) by maize.**<sup>22</sup>

Yield potential (t/ha):	Dryland			Irrigation								
	Grain			Silage			Grain			Silage		
	Low	Mid	High	Low	Mid	High	Low	Mid	High	Low	Mid	High
	2.5	5	7.5	22	37	52	10	12.5	15	65	75	86
Nitrogen	40	80	120	68	136	204	160	200	240	272	340	408
Phosphorus	9	17	25	13	26	36	32	39	46	46	55	65
Potassium	11	22	32	65	112	157	41	51	60	207	245	284

Source: Pacific Seeds Yearbook 2006/2007

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D Plénet, G Lemaire (1999) Relationships between dynamics of nitrogen uptake and dry matter accumulation in maize crops. Determination of critical N concentration. *Plant and Soil* 216.

## 5.8 Nitrogen

Nitrogen is by far the most important nutrient for producing high-yielding crops, but the need for other elements should not be forgotten. If a soil is deficient in even a minor nutrient, high levels of N will not overcome this deficiency.

Because N is the most important nutrient, its good management is essential. Not only is there a need to apply enough to feed the crop, it also needs to be available at crucial growth stages.

Applied N can be lost before the plant can use it, by leaching, denitrification (waterlogging or an anaerobic environment) and immobilisation by micro-organisms. Nitrogen is an essential component of organic compounds, protein, nucleic acids and

<sup>21</sup> Growth potential. Corn grower's workshop. Pioneer Hi-Bred Australia. [http://www.pioneer.com/CMRoot/International/Australia\\_Intl/Publications/Corn\\_Workshop\\_Book.pdf](http://www.pioneer.com/CMRoot/International/Australia_Intl/Publications/Corn_Workshop_Book.pdf)

<sup>22</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries. <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

## SECTION 5 MAIZE

TABLE OF CONTENTS

FEEDBACK

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[G Schwenke \*et al.\* \(2012\) Nitrogen volatilisation losses: how much N is lost when applied in different formulations at different times. GRDC Update Papers.](#)

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[ENTEC—Benefits in maize. Incitec Pivot fertilisers.](#)

[C Dowling \(2014\) Measuring nitrogen is first step to lifting efficiency. GRDC Ground Cover Issue 112.](#)

[T Dixon \(2014\) Denitrification: the latest chapter in the N story. GRDC Ground Cover Issue 108.](#)

chlorophyll. If removing the whole crop for silage, you will remove ~75% more N than for grain production.<sup>23</sup>

Rates of applied N greatly depend on the yield potential of the soil situation.

A deep soil-N test can provide useful information on available N for the crop. The N fertiliser needed may then be pre-applied and/or applied at planting, with topdressing or side-dressing to fill the total requirements.

Post-emergence applications are useful for irrigated crops or where heavy rain falls after emergence. If the total amount of fertiliser to be applied is side-dressed and application is delayed beyond the first 4 weeks after sowing, some yield potential may be lost (refer to Figures 9 and 13).

Nitrogen is very mobile in the soil and losses through leaching can be large. Denitrification losses can also be substantial in wet soils. The techniques of split N application and/or water-run N can be used to advantage under these conditions.

Two other points need to be considered when determining N application rates. First, the efficiency of uptake of fertiliser N is often only ~50%. Second, organic (soil) N is ~15–20% more effective than applied fertiliser N for crop growth. This latter point has important management implications for crop rotations and residual N in the soil.

A grain crop of 11 t/ha (green chop of 70 t/ha) will take up only 35% or 95 kg of its total N requirement during the first 6 weeks after emergence. The next 4 weeks (prior to and during silking) will see 53% of the total N requirements (145 kg) taken up.

When calculating an N budget for maize, an efficiency of ~50% should be used for pre-plant application of inorganic N fertilisers, and a higher efficiency can be used in split applications. Discuss with your agronomist.

Uptake peaks at 4 kg N/ha/day, placing huge demands on fertiliser availability and grower management.

Nitrogen deficiency shows in several ways. When young maize is short of N, the whole plant is pale yellowish green, small, and has spindly stalks. Phosphorus deficiency can also cause plants to purple with stress pigment.

Later, beginning with the bottom leaves, the typical V-shaped yellowing from the tips of the leaves shows.

The greater the N deficiency, the greater the number of bottom leaves affected. Small cobs, often with bare tips, result when N deficiencies occur during silking and grainfill.<sup>24</sup>

Department of Agriculture, Fisheries and Forestry Queensland (QDAF) has produced a rule of thumb for N application in different regions of the state (Table 3).

**Table 3: Nitrogen application rates for dryland and irrigated maize in Queensland (kg/ha).**

Area	Dryland	Irrigated
Atherton Tablelands	0–80	–
Wet tropical coast	130–180	–
Central Queensland	0–40	80–200
Darling Downs <sup>A</sup>	0–180	150–300
Moreton	–	100–200
South Burnett	0–50	80–200

<sup>A</sup> Maximum rate for growers aiming for a 7 t/ha dryland crop or 10 t/ha irrigated crop from ground that has been cultivated for >25 years and has a history of summer crops (such as sorghum, maize, millet, sunflower, cotton) or has been double-cropped with winter cereals

23 Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09. Pacific Seeds Pty Ltd. <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

24 Growth potential. Corn grower's workshop. Pioneer Hi-Bred Australia. [http://www.pioneer.com/CMRoot/International/Australia\\_Intl/Publications/Corn\\_Workshop\\_Book.pdf](http://www.pioneer.com/CMRoot/International/Australia_Intl/Publications/Corn_Workshop_Book.pdf)

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[M Bell \*et al.\* \(2014\) Changing nutrient management strategies in response to declining background fertility. GRDC Update Papers.](#)

[J Laycock \(2014\) Economics and management of P nutrition and multiple nutrient decline. GRDC Update Papers.](#)

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[GRDC \(2012\) Phosphorus management. GRDC Crop Nutrition Fact Sheet.](#)

[M Bell \*et al.\* Improving phosphorus fertiliser management on southern Queensland grain farms. Southern Queensland Farming Systems Project. DEEDI Qld.](#)

Symptoms of N deficiency include:

- light green or yellowish leaves, often with a V-shaped yellow area at tips of leaves
- premature drying along the midrib and leaf tips
- stunted and slow-flowering plants
- short and often poorly filled ears.<sup>25</sup>

## 5.9 Phosphorus

Phosphorus is an essential element in the development and growth of the maize plant. It is also important in the transfer of energy within the plant.

Phosphorus is quite immobile in the soil, so it is important to place it close by the plant line (5 cm to the side and 5 cm below the seed) so that the young plant roots have ready access. Under cool and wet conditions early in the season, coupled with high-pH soils, young maize plants often cannot access enough P until conditions improve.<sup>26</sup> This immobility also means that P can be successfully banked in clay soils so remaining P may be available for subsequent crops.

The QDAF guidelines for P application are presented in Table 4.

**Table 4:** Phosphorus application rates for dryland and irrigated maize in Queensland (kg/ha).

Area	Dryland	Irrigated
Atherton Tablelands	0–35	–
Wet tropical coast	0–35	–
Central Queensland	0–20	0–20
Darling Downs	9–15	0–15
Moreton	–	0–15
South Burnett	0–20	0–40

Symptoms of P deficiency include:

- purplish coloured leaves
- plants with stunted growth
- delayed flowering
- poorly developed root systems
- reduced kernel size and number.<sup>27</sup>

Soil analysis results are useful when developing a P-fertiliser program. In some soils, P can react with other soil components and become unavailable to plants.

Typically, recovery is seldom more than 15–20% of P applied, even under good conditions. Phosphorus is vital in early root and seedling development.

For normal growth, young plants need a higher percentage of P in their tissues than they will later in the season. In addition, P is not mobile (the opposite of N) and does not leach out of soils with clay content. This allows all of the P to be applied prior to or at planting so that the roots may have access to the fertiliser.

Uptake of P in plants can be restricted by poor root establishment (e.g. compaction, planting slot smearing) and cold wet conditions, which may occur with early plantings and can result in poor root vigour. Starter fertiliser will help in these situations.

25 QDAF (2012) Nutrition, irrigation and weeds for maize. Department of Agriculture, Fisheries and Forestry Queensland. <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/nutrition-irrigation>

26 Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09. Pacific Seeds Pty Ltd. <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directrouter.com>

27 QDAF (2012) Nutrition, irrigation and weeds for maize. Department of Agriculture, Fisheries and Forestry Queensland. <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/nutrition-irrigation>



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[A Mollier, S Pellerin \(1999\) Maize root system growth and development as influenced by phosphorus deficiency. \*Journal of Experimental Botany\* 50.](#)

[J Zhu \*et al.\* \(2005\) Topsoil foraging and phosphorus acquisition efficiency in maize \(\*Zea mays\*\). \*Functional Plant Biology\* 32.](#)

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[Sulfur. Incitec Pivot Fertilisers.](#)

<http://www.regional.org.au/au/asa/1985/concurrent/cereal-nutrition/p-08.htm>



If P deficiency is going to occur, it will appear before the plants are 65 cm tall. It is characterised by slow, stunted growth, plants that are very dark green with reddish purple leaf tips and margins, and stems that can show a purple coloration. As the plant develops, plant maturity will be delayed, root systems will be limited and silks will emerge slowly.

A grain crop of 11 t/ha (70 t/ha of green chop) takes up about 30% or 15 kg of its P requirements during the first 55 days. Peak uptake of 0.75 kg/ha.day occurs during 7–10 weeks after emergence, with total uptake being ~50 kg.<sup>28</sup> This causes a net loss from most P-fertiliser regimes in the northern region; if growers are looking at replacement rates for P, or for P banking, then P application rates need to be increased.

### 5.10 Sulfur

Sulfur is a constituent of amino acids, vitamins and enzymes. Traditionally, most Australian soils have been thought to have acceptable levels of S. However, ongoing research has shown that not only are levels lower in some areas of northern NSW and the Darling Downs with a long cropping history, but also that the depth of S in the soil reserves can affect availability. Responses occur in soils that are low in organic matter and particularly under cool and wet conditions early in the plant's life.<sup>29</sup>

Some soils on the Darling Downs and Liverpool Plains (intensively farmed for >20 years) may show responses to S. Usually, 8–10 kg/ha of S is adequate. Gypsum at 200–400 kg/ha every 3 years can be the most economical form of S application; however, it is not immediately available and the solubility rate will depend on the quality of the gypsum.

Because of the mobility of S, it is important to know where it lies in the profile. If the gypsum line is below 60 cm, its S is unlikely to be too deep to be available to the crop in the early stages of growth.

Symptoms of S deficiency include:

- pale green or yellow young plants with only limited stunting
- pale green-yellow upper leaves on older plants, with the lower leaves remaining green (the opposite of N deficiency).<sup>30</sup>

Sulfur originates from organic matter and is normally very mobile in the soil. Typical deficiency symptoms of interveinal chlorosis and stunting are usually most severe in the seedling stage. Use of a starter fertiliser containing S should correct any problems.<sup>31</sup>

### 5.11 Potassium

Potassium is important in the maize plant for the circulation of sugars, starch formation, N uptake, photosynthesis, enzyme activation, lodging resistance, disease resistance and grainfill.

Soil tests may show good reserves of K but not always in a form accessible to the plant. Potassium, like P, is usually applied pre-planting or at planting in an easily accessible band. Potassium is the element that is taken up the quickest by a growing maize plant (80% by tasselling).

Potassium is often overlooked by silage growers, and hay producers, with a lot of K contained in the stover of the plant. A maize grain crop of 10 t/ha uses ~39 kg K, but

28 Growth potential. Corn grower's workshop. Pioneer Hi-Bred Australia. [http://www.pioneer.com/CMRoot/International/Australia\\_Intl/Publications/Corn\\_Workshop\\_Book.pdf](http://www.pioneer.com/CMRoot/International/Australia_Intl/Publications/Corn_Workshop_Book.pdf)

29 Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09. Pacific Seeds Pty Ltd. <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

30 QDAF (2012) Nutrition, irrigation and weeds for maize. Department of Agriculture, Fisheries and Forestry Queensland. <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/nutrition-irrigation>

31 Growth potential. Corn grower's workshop. Pioneer Hi-Bred Australia. [http://www.pioneer.com/CMRoot/International/Australia\\_Intl/Publications/Corn\\_Workshop\\_Book.pdf](http://www.pioneer.com/CMRoot/International/Australia_Intl/Publications/Corn_Workshop_Book.pdf)



**i MORE INFORMATION**

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**i MORE INFORMATION**

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[J White \(2003\) Potassium nutrition in Australian high-yielding maize production systems—a review. Australian Maize Conference.](#)



the same crop, if taken off for silage, will deplete the soil of 183 kg K.<sup>32</sup> In areas with a long history of maize production in the northern region, K deficiency in other crops is becoming more common.

Soil testing and test strips are recommended to help in the early detection of K deficiency.

Potassium application rates recommended by QDAF are presented in Table 5.

**Table 5: Potassium application rates for dryland and irrigated maize in Queensland (kg/ha).**

Area	Dryland	Irrigated
Atherton Tablelands	0–50	0–50
Wet tropical coast	0–50	
Central Queensland	0–25	0–50
Darling Downs	0–50	0–50
Moreton	–	0–50
South Burnett	0–30	0–50

Symptoms of K deficiency include:

- a scorched appearance on the outer leaf edges of young plants
- yellow to brown discoloration on lower leaves
- a crop with a greater tendency to lodge
- a crop with small ears that fail to fill at the tip.<sup>33</sup>

Maize requires large amounts of K in quantities similar to N.

Potassium is essential for vigorous growth, yet is not a part of proteins and other organic compounds. It is vital to the structure and efficiency of the functioning of the maize plant for the production and movement of sugars to the developing ears.

Potassium does not leach to the same extent as N, nor does it become tied up in unavailable or slowly available forms to the degree that P does. However, like P, it should not be placed in the surface layer, which will regularly dry out and the K will be unavailable to the growing plant. Any applied fertiliser K will be absorbed by the clay lattice before it is available to plant.

Applications of K can be carried out at any time during land preparation. Some forms of K fertilisers need to be applied well in advance of planting to be available to the growing crop.

A grain crop of 11 t/ha (green chop of 70 t/ha) takes up >50% or 117 kg of its K requirement of 225 kg in the first 55 days. The young seedling does not require much K, but the rate of uptake climbs rapidly to a peak in the 3 weeks leading to tasselling. Uptake of K peaks at ~4 kg/ha.day during this period, and by silking 75% of the total K has been taken up.

A deficiency of K shows as yellowing and dying of leaf margins, beginning at the tips of the lower leaves. Symptoms appearing at an early stage mean that the total soil supply is low or that the root system is severely restricted, for example a compacted soil layer or subsoil constraints.<sup>34</sup>

32 Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09. Pacific Seeds Pty Ltd. <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

33 QDAF (2012) Nutrition, irrigation and weeds for maize. Department of Agriculture, Fisheries and Forestry Queensland. <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/nutrition-irrigation>

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## 5.12 Long-fallow disorder

Soils naturally contain beneficial fungi that help the crop to access nutrients such as P and Zn. They form a symbiotic relationship with the crop that helps developing roots access nutrients such as P and Zn.

The combination of the fungus and crop root is known as arbuscular mycorrhiza(e) (AM), previously VAM. Many different species of fungi can have this association with the roots of crops. Many that are associated with crops also form structures called vesicles in the roots.

The severe reduction or lack of AM shows up as long-fallow disorder—the failure of crops to thrive despite adequate moisture. Ongoing drought in the 1990s and beyond has highlighted long-fallow disorder where AM have died out through lack of host plant roots during periods of long fallow. As cropping programs restart after dry years, a yield drop is likely from reduced AM levels, making it difficult for the crop to access nutrients.

Long-fallow disorder is typified by poor crop growth. Plants seem to remain in their seedling stages for weeks and development is very slow.

Benefits of good AM levels are:

- improved uptake of P and Zn
- improved crop growth
- greater drought tolerance
- improved soil structure
- greater disease tolerance.

In general, the benefits of AM are greater at lower soil P levels because AM increase a plant's ability to access this nutrient. Sorghum has a medium dependency on mycorrhizae, and crops with higher dependency benefit more from AM (Table 6).<sup>35</sup>

**Table 6:** *Dependency of various crop species on mycorrhizae (value decreases as the phosphorus level of the soil increases).*

Mycorrhizal dependency	Potential yield loss without mycorrhiza (%)	Crops
Very high	>90	Linseed
High	60–80	Sunflower, mungbean, pigeon pea, maize, chickpea
Medium	40–60	Sudan grass, sorghum, soybean
Low	10–30	Wheat, barley, triticale
Very low	0–10	Panicum, canary grass
Nil	0	Canola, lupins

## 5.13 Micronutrients

### 5.13.1 Zinc

Maize is susceptible to zinc (Zn) deficiency. Zn may be applied to soil or as foliar fertiliser.

For soil application, apply 30 kg/ha of Zn sulfate monohydrate or zinc oxide into the soil at least 3 months before planting. This may correct the deficiency for up to 8 years.

<sup>35</sup> QDAF (2010) Nutrition—VAM and long fallow disorder. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/nutrition-vam>

## SECTION 5 MAIZE

TABLE OF CONTENTS

FEEDBACK

For foliar application, apply 2–4 weeks after emergence. A second application may be required 2 weeks later. Apply 1–1.5 kg of zinc sulfate heptahydrate and an equal amount of urea in 100 L of water. Apply at a rate of 100 L/ha.

If the water is hard (i.e. with high carbonate levels), the water will turn cloudy as insoluble zinc carbonate is produced. Trickle in sulfuric acid (e.g. battery acid) as the tank is filling. The rate is 50 mL/100 L. This will make the Zn available to plants.

Zn chelates are very compatible with herbicides and can be used at sowing in a mix as a fluid starter with the seed. Read the Zn product and herbicide labels to ensure compatibility.

Other Zn-based products are available. If these are used, follow the label directions.

Symptoms of Zn deficiency include:

- light streaking followed by a broad whitish band, starting slightly in from the leaf edge and extending to the midrib
- leaf edges, midrib and tip that remain green
- plants stunted with short internodes
- new leaves with sometimes nearly whiteleaf edges and stalks of a purplish colour.<sup>36</sup>

Zn is a growth regulator. Maize is particularly sensitive to soil Zn deficiencies, particularly on heavy clay soils with a high pH and under cool conditions early in the plant life. Cut areas will often be deficient in Zn for a few years. Most of the Zn is taken up in the first 4 weeks of the plant's life; therefore, it must be available from day one.

Once Zn deficiency symptoms are evident, yield losses are already being experienced.

Maize growers cropping on susceptible soils should implement a long-term program to overcome Zn deficiencies, using zinc oxide or zinc sulfate monohydrate well in advance. Zn can be applied by water injection using zinc sulfate heptahydrate, meaning it is readily available. Often, foliar applications are applied when symptoms are evident, and two applications may be required for a severely affected crop to recover.

Fertiliser companies now have Zn in some starter fertiliser blends, which lends itself to an ongoing program.<sup>37</sup>

Maize plants are rated as having moderate to high susceptibility to Zn deficiency.

Zn is necessary early in the plant's growth, during the first 3 weeks. Responses to applied N and P may be affected if the level of available Zn is low.

Soils with a high pH (>7.0), eroded soils, or land-formed soils are most at risk of Zn deficiency.

As with other nutrients, yield losses can occur before visible symptoms occur. Typical symptoms are light, parallel striping followed by a broad whitish band starting slightly in from the leaf edge and extending to the midrib. The leaf edges, midrib and tip of the leaf remain green.

Soil applications of Zn are expected to last several years, with rates of 10–20 kg Zn/ha effective for 4–5 years. Depending on the form of Zn used, applications may need to be made well in advance of the crop.

Foliar applications during waterlogging periods early in the crop's development can be a useful management tool in helping the crop overcome associated stress.

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[Nutrient sources for crops. Incitec Pivot Fertilisers.](#)



Water injection and/or foliar (1% solution) applications of Zn generally use zinc sulfate heptahydrate or chelated zinc for overcoming Zn deficiencies. Foliar applications generally need two sprays about 7–10 days apart, 2–3 weeks after emergence.<sup>38</sup>

### 5.13.2 Molybdenum

Seed normally has sufficient molybdenum (Mo), although deficiencies can occasionally occur in acid soils, especially those that are highly leached. Mo deficiency can be treated with a foliar spray of sodium molybdate at 300 g/ha. This is applied when there is sufficient leaf area (e.g. 30 days after planting).

Symptoms of Mo deficiency include:

- tips of the lower leaves turning yellow, browning off and dying shortly after plant emergence
- many plants in a crop dying completely and others being short and stunted.

Deficiencies can be corrected by application of Mo mixed with other fertilisers. This may correct the deficiency for up to 5 years.<sup>39</sup>

The main function for Mo in a maize plant is in the enzyme system for nitrate reduction. Mo deficiency is not usually a problem, but some coastal acid soils can be deficient and the situation is easily corrected with the addition of molybdenised superphosphate.<sup>40</sup>

### 5.13.3 Magnesium

Magnesium (Mg) deficiency is usually associated with strongly acid, sandy soils in moderate to heavy rainfall areas where the Mg can be leached from the soil.

Characteristic symptoms are yellow streaking of the lower leaves between the veins, sometimes followed by dead, round spots. The older leaves can become reddish purple. Broadcast applications of dolomite should be the most economical long-term treatment. Magnesium sulfate (Epsom salts) is used if a foliar spray is needed.<sup>41</sup>

38 Growth potential. Corn grower's workshop. Pioneer Hi-Bred Australia. [http://www.pioneer.com/CMRoot/International/Australia\\_Intl/Publications/Corn\\_Workshop\\_Book.pdf](http://www.pioneer.com/CMRoot/International/Australia_Intl/Publications/Corn_Workshop_Book.pdf)

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# Weed control

Weeds compete for nutrients and water, which can contribute to crop stress if not properly managed. Weeds may also create harvest problems and increase marketing costs. Crop rotations, planting into weed-free seedbeds, inter-row cultivations and herbicides are all techniques for controlling weeds. To prevent significant yield loss, weeds must be controlled within 4–5 weeks of planting.

Herbicides may be applied at pre-plant, pre-emergence, post-plant or post-emergence. Before using herbicides, always read the label. Do not use the herbicides Dual® (active ingredient S-metolachlor) or Primextra® (S-metolachlor + atrazineDualGold metalochlor) or PrimextraGold (metolochlor + atrazine) with waxy maize varieties.<sup>1</sup>

Always check rates, the types of weeds controlled, and application and safety guidelines on the label.<sup>2</sup>

Good weed control is very important for high yields in maize, as it is with other summer crops. Weeds compete very strongly for moisture, nutrients and light. Grass weeds are the most competitive and must be eliminated early. However, broadleaf weeds will also compete strongly with maize. Maize is quite sensitive to weed competition in the early stages of growth until it reaches about 0.8 m in height.

As well as a detrimental effect on your maize crop yield, weeds can create problems at harvest time by blocking harvesting fronts and sieves, or by causing dockage in payments when the grain is delivered. In severe cases, weeds can cause the grain to be rejected for receipt by the customer.

Weed control can be carried out by either mechanical or chemical means, or the combination of both.<sup>3</sup>

## 6.1 Competition from weeds

Yield losses from weed competition in maize vary from negligible to total crop loss.

Weeds have the greatest competitive effect on maize in the first 3–4 weeks after sowing, so early control is essential. Once the maize crop has reached 80–100 cm high it can effectively compete with most weeds.

Maize is sensitive to moisture stress, so the early control of weeds is particularly important in non-irrigated crops. Weeds can cause reductions in yield through competition for water, sunlight and nutrients.

Weeds such as bellvine (*Ipomoea* spp.) can also cause significant problems at harvest, whereas noogoora burr (*Xanthium pungens*) and *Datura* species can cause weed seed contamination of grain, leading to rejection by the buyer.

Failure to control weeds can also lead to a narrowing of enterprise options for the future. For example, failure to control noogoora burr and *Datura* in a maize crop will eliminate sunflowers as a future option due to limited control options.

<sup>1</sup> QDAF (2012) Nutrition, irrigation and weeds for maize. Department of Agriculture, Fisheries and Forestry, Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/nutrition-irrigation>

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Successful management of weeds in maize crops comes through planning, paddock selection, timeliness of operations and a willingness to use a wide range of weed-management options.

Reliance on a single method of weed control will lead to a ‘species shift’ or herbicide resistance if there is a major reliance on one herbicide group. A species shift is where one control technique is repeatedly used, leading to an increase in numbers of one or more weed species not controlled by that technique. An example is the continued use of metolachlor (Dual®) without other weed-management techniques, which leads to an increase in broadleaf species such as pigweed (*Portulaca oleracea*) or *Datura*.<sup>4</sup>

## 6.2 Main weed species of concern in maize crops

Although maize is grown across a wide and varied geographical area, weed-management techniques remain common across this range of environments. Tables 1–4 list some of the main weed species encountered in maize in eastern Australia.<sup>5</sup>

**Table 1:** Grass weeds of maize by region.

Grasses	North Qld	Sth Burnett/ Darling Downs	Northern NSW	NSW North Coast	Riverina/ Victoria
Mossman river grass ( <i>Cenchrus</i> spp)	✓	✓			
Crowsfoot grass ( <i>Eleusine indica</i> )	✓	✓	✓	✓	
Barnyard grass ( <i>Echinochloa</i> spp)		✓	✓	✓	✓
Summer grass ( <i>Digitaria</i> spp)	✓	✓	✓	✓	✓
Guinea grass ( <i>Panicum maximum</i> )	✓	✓			
Pigeon grass ( <i>Setaria</i> spp)		✓	✓	✓	✓
Liverseed grass ( <i>Urochloa panicoides</i> )		✓	✓		
Stinking lovegrass ( <i>Eragrostis cilianensis</i> )		✓	✓		✓
Johnson grass ( <i>Sorghum halepense</i> )	✓	✓	✓	✓	✓
Rhodesian sudan grass ( <i>S bicolor</i> ssp <i>arundinaceum</i> )	✓				
Couch grass ( <i>Cynodon dactylon</i> )	✓	✓	✓	✓	✓
Water couch ( <i>Paspalum distichum</i> )	✓			✓	✓

<sup>4</sup> A Storrie (1997) Australian maize. Kondinin Group.

<sup>5</sup> A Storrie (1997) Australian maize, Kondinin Group.

## SECTION 6 MAIZE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

**Table 2:** *Sedges and rushes.*

Sedges	North Qld	Sth Burnett/ Darling Downs	Northern NSW	NSW North Coast	Riverina/ Victoria
Nutgrass ( <i>Cyperus rotundus</i> )	✓	✓	✓	✓	
Umbrella sedge ( <i>Cyperus eragrostis</i> )				✓	✓

**Table 3:** *Broadleaf weeds in maize by region.*

Broadleaf weeds	North Qld	Sth Burnett/ Darling Downs	Northern NSW	NSW North Coast	Riverina/ Victoria
Amaranth ( <i>Amaranthus</i> spp)	✓	✓	✓	✓	
Annual ground cherry ( <i>Physalis angulata</i> )		✓	✓	✓	
Apple of Peru ( <i>Nicandra physalodes</i> )	✓	✓		✓	
Bathurst burr ( <i>Xanthium spinosum</i> )		✓	✓	✓	✓
Bellvine ( <i>Ipomoea</i> spp)	✓	✓		✓	
Blackberry nightshade ( <i>Solanum nigrum</i> )	✓	✓	✓	✓	✓
Bladder ketmia ( <i>Hibiscus trionum</i> )		✓	✓	✓	✓
Caltrop ( <i>Tribulus</i> spp)		✓	✓		✓
Cobbler's peg ( <i>Bidens pilosa</i> )	✓	✓	✓	✓	
Common verbena ( <i>Verbena</i> spp)	✓	✓	✓	✓	
Euphorbia/Spurge ( <i>E. davidii</i> or <i>E. dentata</i> )		✓	✓		
Fat hen ( <i>Chenopodium album</i> )	✓	✓	✓	✓	
Mintweed ( <i>Salvia reflexa</i> )		✓	✓	✓	
Noogoora burr ( <i>Xanthium pungens</i> )	✓	✓	✓	✓	
Pigweed ( <i>Portulaca oleracea</i> )		✓	✓	✓	✓
Sesbania pea ( <i>Sesbania</i> spp)	✓	✓	✓		✓
Sida ( <i>Sida</i> spp)		✓	✓		

## SECTION 6 MAIZE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Broadleaf weeds	North Qld	Sth Burnett/ Darling Downs	Northern NSW	NSW North Coast	Riverina/ Victoria
Sow thistle ( <i>Sonchus</i> spp)		✓	✓	✓	✓
Starburr ( <i>Ancanthospermum hispidum</i> )	✓	✓		✓	✓
Stinking roger ( <i>Tagetes minuta</i> )	✓	✓		✓	
Thornapple ( <i>Datura</i> spp)		✓	✓		
Turnip weed ( <i>Rapistrum rugosum</i> )		✓	✓		✓
Wandering jew ( <i>Commelina benghalensis</i> )		✓		✓	
Wild gooseberry ( <i>Physalis minima</i> )		✓	✓	✓	

**Table 4:** Herbicides registered in Australia for use in maize.

Herbicide	Queensland and NSW	Victoria	Tasmania, SA and WA
<b>Pre-plant</b>			
Eptam (EPTC)	✓	✓	
atrazine (various)	✓	✓	✓
<b>Post-plant pre-emergence</b>			
atrazine (various)	✓	✓	✓
atrazine + Dual	✓	✓	✓
atrazine + Stomp	✓	✓	✓
Dual (metolachlor)	✓	✓	✓
Primextra (atrazine + Dual)	✓	✓	
Stomp (pendimethalin)	✓	✓	✓
Primextra + Dual	✓	✓	
linuron (various)	✓	✓	✓
Ramrod (propachlor)	✓	✓	✓
<b>Post-emergence</b>			
2,4-D (various)	✓	✓	✓
atrazine (various)	✓	✓	✓
atrazine + 2,4-D	✓	✓	✓
atrazine + dicamba	✓	✓	✓
atrazine + Tordon 75-D	✓		
dicamba (Banvel 200)	✓	✓	✓
linuron (various)	✓	✓	✓
MCPA (various)	✓	✓	

Herbicide	Queensland and NSW	Victoria	Tasmania, SA and WA
Tordon 75-D (picloram + 2,4-D)	✓		
<b>Pre-harvest</b>			
2,4-D (various)	✓		

### 6.3 Forms of weed control

A wide range of techniques should be used if sustainable agricultural production is the long-term aim.

Weed control begins with the previous crops and pastures where weeds should have been prevented from setting seed. Planning with earlier application of herbicides or selecting a 'clean' paddock can help prevent major problems.<sup>6</sup>

#### 6.3.1 Mechanical weed control

Maize is usually planted in rows up to 1 m apart, and therefore, inter-row cultivation can be practiced. Inter-row cultivation can be done until the maize crop reaches about 0.75 m in height. After that, the crop canopy closes over and the maize competes well with weeds.

Inter-row cultivation must be shallow to prevent root pruning of the crop but can sometimes be advantageous in maize crops to encourage root development and deeper root systems.. Wet conditions may prevent cultivation at critical times and/or cause transplanting of weeds.<sup>7</sup>

#### 6.3.2 Mechanical and chemical weed control

Band spraying of chemicals in the crop row combined with inter-row cultivation is a widely used practice in all types of summer crops.<sup>8</sup>

#### 6.3.3 Chemical weed control

Several chemicals are available that will give very good weed control through the life of the maize crop if used correctly. Always read the label before starting to spray).<sup>9</sup> Maize crops are annual in nature and weed escapes are very common between physiological maturity and harvest.

### 6.4 Farm hygiene

Controlling weed infestations along fence lines, roadways, channels and buildings will minimise weed spread. New weeds will infest these areas first, being carried in by machinery or livestock. They are also the sources of seed to re-infest fields.

These areas can be kept weed-free by sowing perennial pasture species, which can be periodically slashed or managed with a combination of herbicides and cultivation.<sup>10</sup> It is important not to choose a *Chloris* sp. which are currently major source of summer grass resistance such as feathertop Rhodes grass and windmill grass.

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6 A Storrie (1997) Australian maize, Kondinin Group.

7 Growth potential. Corn growers' workshop. Pioneer Hi-Bred Australia, [http://www.pioneer.com/CMRoot/International/Australia\\_Intl/Publications/Corn\\_Workshop\\_Book.pdf](http://www.pioneer.com/CMRoot/International/Australia_Intl/Publications/Corn_Workshop_Book.pdf)

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9 [http://www.pioneer.com/CMRoot/International/Australia\\_Intl/Publications/Corn\\_Workshop\\_Book.pdf](http://www.pioneer.com/CMRoot/International/Australia_Intl/Publications/Corn_Workshop_Book.pdf)

10 A Storrie, Australian Maize, Kondinin Group 1997

## 6.5 Crop rotation

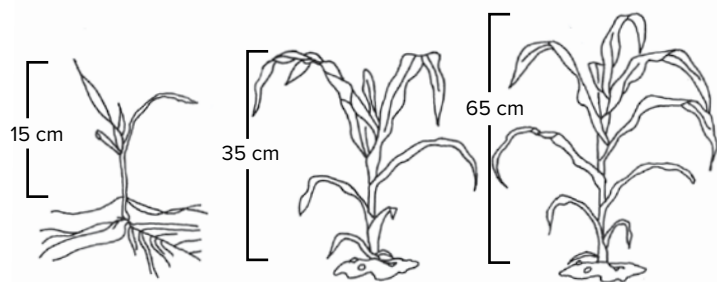
Rotations should be flexible enough to take account of variations in markets and weather.

The ideal is to alternate between broadleaf and cereal crops, and well-managed pastures. This allows cultivation, herbicides and grazing to be used. For example, alternating between summer crops and winter crops with the occasional long fallow will prevent the buildup of any one weed species.<sup>11</sup>

Do not plant sorghum or maize into paddocks with a high feathertop Rhodes grass seed bank population. Pre-emergent herbicide options such as metolachlor are unlikely to provide full season residual control, even at the highest application rate — especially in wet seasons. Late season germinations can establish after the pre-emergent herbicide has broken down.<sup>12</sup>

## 6.6 Maize growth stages

Figure 1 describes the growth stages of maize.



### Stage V2 – Two leaf stage

Only count leaves which have the leaf collar visible. Occurs about one week after emergence. Growing point below soil surface – plants survive hail and light frosts. First set of secondary roots developed. Weeds start to reduce yields significantly. Start spraying most post-emergent herbicides.

### Stage V5 – Five leaf stage

Occurs about three weeks after emergence. Growing point at soil surface. Tassel and ears initiated. Total leaf number determined. Two sets of secondary leaves developed. Weeds significantly reduce yields. Use drop nozzles for most post-emergent herbicides.

### Stage V8 – Eight leaf stage

Occurs four to five weeks after emergence. Two lowest leaves may be lost. The leaf stage is now determined by splitting the stem lengthwise. Use the first node above the first elongated internode (usually the fifth leaf node) as the reference point. Growing point about 5 to 7 cm above soil surface. Yields may be reduced by hail and frosts. Too late to use most post-emergent herbicides.

## MORE INFORMATION

[J Fleming et al. \(2013\) Weed control in summer crops 2012–13. NSW Department of Primary Industries.](#)

[Growth potential. Corn growers' workshop. Pioneer Hi-Bred Australia.](#)

**Figure 1: Maize growth stages.**

Source: NSW DPI

<sup>11</sup> A Storrie (1997) Australian maize. Kondinin Group.

<sup>12</sup> M Congreve, R Daniel (2015) Get the first second and third punch in on Feathertop Rhodes Grass. GRDC Update Papers 3 August 2015, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Get-the-first-second-and-third-punch-in-on-Feathertop-Rhodes-Grass>



**i MORE INFORMATION**

Pre-emergent herbicides part of the solution but much still to learn

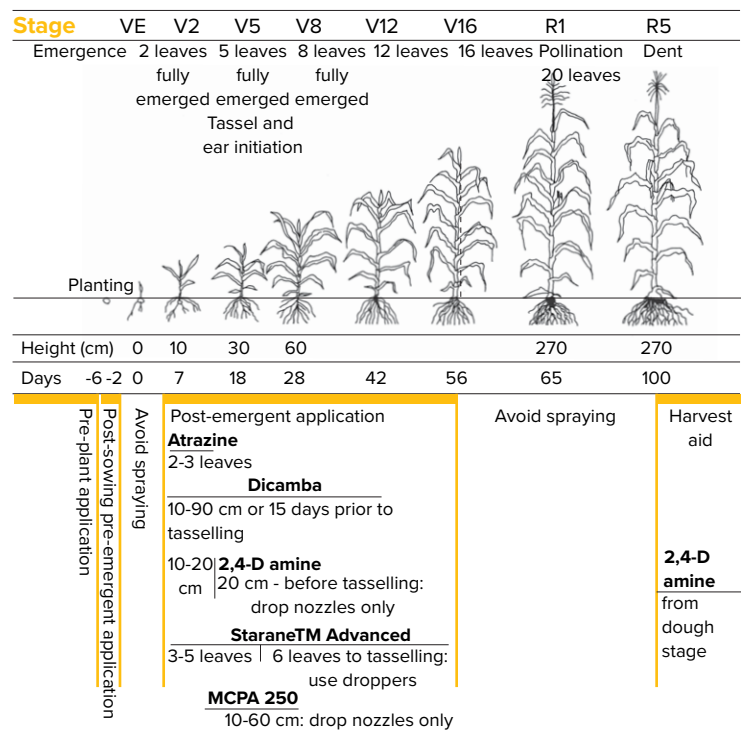
## 6.7 Pre-emergent herbicides

Pre-plant or pre-emergent weed control of grasses is essential in maize. Similarly, broadleaf weed control is preferable at this stage. In seeking flexible cropping options, farmers often avoid the use of residual herbicide, especially for grass control.<sup>13</sup>

Summer weeds and grasses are very aggressive and compete with young maize plants for moisture, nutrition and light. Therefore, early weed control is essential in maize crops before the canopy shades the soil surface.

Traditional cultivation will help to reduce weed competition very early on, but not post-planting. Inter-row cultivation on its own or coinciding with side dressing is another method of mechanical weed control.

By far the most efficient and effective form of weed control is use of herbicides. A very good range of herbicides is registered for weed control in maize, ranging from pre-emergent through to post-emergent (Figure 2).



**Figure 2: Timing of herbicide application in maize.**

Source: NSW Agriculture

Always read the application directions on the label. Some residual herbicides have plant-back restrictions for following crops, so careful planning of a herbicide program is required to ensure cropping options are not restricted.

It is therefore important to understand the herbicide history of the particular paddocks—a residual herbicide to which maize is sensitive may have been applied on a previous crop.

<sup>13</sup> J Fleming, T McNee, T Cook, B Manning (2012) Weed control in summer crops 2012–13. NSW DPI Management Guide. NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0008/248471/Weed-control-in-summer-crops-2012-13.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0008/248471/Weed-control-in-summer-crops-2012-13.pdf)

**i MORE INFORMATION**

[http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0008/248471/Weed-control-in-summer-crops-2012-13.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0008/248471/Weed-control-in-summer-crops-2012-13.pdf)

<http://www.nufarm.com/NZ/Maize>

[J Fleming \*et al.\* \(2013\) Weed control in summer crops 2012-13. NSW Department of Primary Industries.](#)

[Top of the crop. A guide to protecting your maize crop and maximising yield. Nufarm Ltd.](#)



Some of the registered herbicides used in maize either on their own or in combination include atrazine, Dual Gold®, Primextra®, Stomp® (pendimethalin), Starane™ Advanced (fluroxypyr), and the hormone chemicals (post-emergent) Starane®, 2,4-D amine, dicamba and Tordon 75D® (picloram + 2,4-D).

For current registered chemicals for use in maize, visit [www.apvma.gov.au](http://www.apvma.gov.au)

Of the hormone chemicals, Starane® (fluroxypyr) is the softest on maize, and attention should be given to the timing of application of these herbicides to ensure that they are applied at the correct stage and the crop is not under stress.

Use of droppers is recommended between the rows to avoid applying chemical to the whorl. Otherwise, damage to the reproductive parts of the plant and lodging can result. For more detailed information on herbicides and their application, contact your local agronomist, reseller or chemical representative.

Farm hygiene should also be maintained around fence lines, storage dams, waterways and channels to keep the weed seedbank in check. Finally, clean crops and surrounding areas will help reduce the buildup of insects and some diseases.<sup>14</sup>

### 6.7.1 Recropping issues with pre-emergent herbicides

Most pre-emergent herbicides are broken down by microbial activity in the soil. A smaller number are broken down primarily by a chemical reaction known as hydrolysis.

The rate of herbicide persistence is usually reported as a DT50 value. DT50 values represent the half-life, or the days for 50% of the herbicide in the soil to breakdown. As this varies for different soils and conditions, the DT50 is often reported as a range of values from different soil types or as an average value across a range of soils.

Herbicides with a DT50 under 30 are often classified as non-persistent as they tend to breakdown relatively quickly. However, at very high rates, some products with low DT50 values can still provide useful pre-emergent activity. An example is s-metolachlor e.g. Dual Gold® (DT50 of approximately 21). In the case of Dual Gold® the use rate in sorghum and maize is 1-2 L/ha (960-1920 gal/ha) which is much higher than required for short term residual weed control, however by applying this high rate, a few months residual control can be achieved before the product dissipates.<sup>15</sup>

### 6.8 Post-plant pre-emergent herbicides

Weeds should be removed from maize within 3-4 weeks of emergence to prevent yield loss. The extent of yield reduction depends on the weed species, weed and crop density, and the size of weeds when control measures are applied. The stages of weed and crop growth are vital factors when planning successful post-emergent herbicide use. Read herbicide labels carefully for these details and information on optimum conditions for spraying.<sup>16</sup>

#### 6.8.1 Imidazolinone technology

The I.T. trait incorporated in some of the hybrid maize range means 'imidazolinone tolerance'. Imidazolinone is a family of herbicides with the potential to control many important weed species that cause yield and quality reduction in many maize-growing regions of Australia.

The I.T. or Clearfield® trait for maize is a non-GMO (non-genetically modified organism), herbicide-tolerant cropping system. I.T. herbicide resistance was developed in

**i MORE INFORMATION**

[J Fleming \*et al.\* \(2013\) Weed control in summer crops 2012-13. NSW Department of Primary Industries.](#)

<sup>14</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09. Pacific Seeds Pty Ltd. <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directrouter.com>

<sup>15</sup> J Cameron, M Congreve (2016) Recropping issues with pre emergent herbicides. GRDC Update Papers 26 February 2016. <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Recropping-issues-with-pre-emergent-herbicides>

<sup>16</sup> J Fleming, T McNee, T Cook, B Manning (2012) Weed control in summer crops 2012-13. NSW DPI Management Guide. NSW Department of Primary Industries. [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0008/248471/Weed-control-in-summer-crops-2012-13.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0008/248471/Weed-control-in-summer-crops-2012-13.pdf)

## MORE INFORMATION

<http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Managing-herbicide-resistant-weeds-in-the-summer-fallow>

M Congreve (2014) [Managing herbicide resistant weeds in the summer fallow. GRDC Update Papers July 2014.](#)

I Rajcan *et al.* (2001) [Understanding maize–weed competition: resource competition, light quality and the whole plant. Field Crops Research Vol. 71.](#)

1988 using traditional plant-breeding techniques. This research isolated a naturally occurring, dominant in nature. This means that an I.T. maize parent line can be crossed to a non-I.T. parent line to produce hybrid seed that has complete tolerance through its dominant nature.

Maize hybrids with the I.T. trait have shown no significant yield penalty compared with conventional hybrids.

In Australia, the herbicide registered for use on I.T. varieties is Lightning® (imazethapyr + imazapyr), a broad-spectrum herbicide for knockdown and residual weed control.

Because of the residual effect of Lightning®, careful consideration should be given to plant-back intervals for crops that follow. Plant-back periods vary depending on the crop to be planted and environmental conditions. Refer to product label for more comprehensive details.<sup>17</sup> Rapid development of grass weed resistance with IMI herbicides is a risk if not used strategically.

[Australian Pesticides and Veterinary Medicines Authority.](#)

## 6.9 Potential herbicide damage effect

Dealing with large numbers of weed in summer fallow is a sign that strategies for seedbank management are not working.

Widespread adoption of no-till farming has seen a species shift to weeds adapted to surface germination.

Over-reliance on glyphosate in the fallow is leading to rapid expansion of glyphosate resistance.

Integrated weed management strategies are available to manage key species present in the summer fallow through the northern grains region. Growers who have zero tolerance to weeds producing seeds can drive seedbanks for many weeds to very low levels within 1–3 years.

Growers who have the weed seedbank under control will save herbicide costs, have greater rotational flexibility, have greater options to use diverse tactics that would otherwise be cost prohibitive, and, by reducing the frequency of herbicide applications, will delay the onset of herbicide resistance.<sup>18</sup>

<sup>17</sup> Pacific Seeds Agronomy Notes

<sup>18</sup> M Congreve (2014) [Managing herbicide resistant weeds in the summer fallow. GRDC Update Papers July 2014, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Managing-herbicide-resistant-weeds-in-the-summer-fallow](http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Managing-herbicide-resistant-weeds-in-the-summer-fallow)

**i MORE INFORMATION**

[K Charleston \(2013\) Maize insect pest management. Northern grains region. QDAF Queensland.](#)

[P Umina \(2014\) Persistent pests: aphids, mites, millipedes and earwigs. GRDC Update Paper.](#)

National Invertebrate Pest Initiative IPM Guidelines <http://ipmguidelinesforgrains.com.au/crops/maize/>

# Insect control

Several pests can attack maize plants during the vegetative, reproduction and grainfill stages, the most significant being the corn earworm or *Helicoverpa* larvae and, in some areas, the two-spotted spider mite. Others that can cause yield loss are the corn aphid, redshouldered (*Monolepta*) beetle, green vegetable bug, locusts and maize weevil.

In seasons when *Helicoverpa* have overwintered and numbers are high early in the season, there is an early egg lay evident by perforated new leaves. Hatching larvae will forage on tassels and silks, and if infestation is severe, they can cut the silks, off reducing seedset. Once the larvae grow, it is uncommon to have more than one in each cob tip. They usually do not do a lot of damage at this stage, unless the numbers are high, and then they may start burrowing into the side of the cob. If this occurs, these cobs are predisposed to cob rots.<sup>1</sup>

Agronomists report that *Helicoverpa* larvae causing cob damage are laid when the tassels and silks are established. Eggs that are laid in the vegetative stage have already finished their life cycle by the time silks and tassels have emerged, so damage to reproductive parts of the plant is generally restricted to developing tassel down in the whorl.

If signs of a large egg lay appear, spray prior to canopy closure. If spraying is left until silking or later, it will be difficult to achieve chemical penetration into the canopy. If you see large larvae (30–50 mm) in the crop, it is too late to spray; they will be nearly impossible to control.<sup>2</sup> Most attempts at controlling *Helicoverpa* damage to cobs are timed at silking and tasseling when neonates have hatched.

Weekly trap catch data for *H. punctigera* and *H. armigera* from locations across all states can now be [viewed online](#). The adjustable bar below the map allows selection of a time period (1 wk, 2 wks, 1 mth, etc). <https://jamesmaino.shinyapps.io/MothTrapVis/>

## 7.1 Maize pests by crop stage

Pests can occur at one or more growth stages.<sup>3</sup>

**Table 1: Maize pests by crop stage.**

Pest	Crop stage			
	Emergence	Vegetative	Silking/ Tasselling	Grainfill
Black field earwig	✓			
Wireworms	✓			
Cutworms	✓			
Maize thrips	✓	✓		
Maize leafhoppers	✓	✓		
Locusts		✓		

1 Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09. Pacific Seeds Pty Ltd. <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>  
 2 Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09. Pacific Seeds Pty Ltd. <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>  
 3 QDAF (2012) Insect pest management in maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/maize#cropstage>



Pest	Crop stage			
	Emergence	Vegetative	Silking/ Tasselling	Grainfill
Whitegrubs		✓		
Armyworm		✓		
Swarming leaf beetles		✓		
Red shouldered leaf beetles		✓		
Green vegetable bugs		✓		✓
Corn aphids		✓		
Helicoverpa		✓	✓	✓
Two spotted mites				✓
Red banded shield bug				✓
Yellow peach moth				✓

## 7.2 Early pests

Planting is the single most important operation in the farming system and opportunities to plant are valuable. Therefore, it is important to ensure that emerging seedlings are protected from seedling pests such as insects and mice.

Attack from these types of pest is sporadic from season to season and field to field, so it is difficult to anticipate their occurrence and numbers. Regular inspection of emerging crops is essential.

Maize is particularly sensitive to variation in plant spacing (the effect of uneven plant spacing in maize is estimated to cost growers on average 400–500 kg/ha). Recently, growers, recognising the importance and yield benefits of even seed spacing, have made efforts to ensure the best result. This effort could be wasted if growers then ignore the risks of early pests.

The most likely seedling pests are ground-dwelling insects such as false wireworm and cutworm, aboveground predators such as northern armyworm and mice, and sapsuckers such as thrips, aphids, field crickets and earwigs.

The best defence against many ground-dwelling insects is an integrated attack that includes good weed control, well-controlled planting depth and evenness, sowing into good moisture, warm soil, and quality seed treated with an insecticide. Even with best practice, the desired result is not guaranteed, and early-planted crops usually come under the most pressure. False wireworms in particular are generally in abundance early in the season, so planting without seed treatment is not recommended.<sup>4</sup>

### 7.2.1 Mice

Mice seem to be increasing in importance as a pest of agricultural crops; damage caused by mice to agriculture is estimated at AU\$10–30 million.

Areas on the eastern and central Darling Downs are already incurring damage in winter crops, and some baiting has already started. The western Downs is at moderate risk and mice numbers around Mungindi are reported as high. Mice like to overwinter in no-till sorghum paddocks and in table drains. As food supply diminishes in these areas, they migrate to winter crops.

### MORE INFORMATION

[RL Nielsen \(1997\) Stand establishment variability in corn. Purdue University.](#)

<sup>4</sup> Early pest of sorghum and maize. Pacific Seeds, <https://www.pacificseeds.com.au/agronomy-tools/summer-solutions.html>



If left uncontrolled, they can cause high levels of damage in the winter crop and can move to the summer crops. Mice tend to cause their worst damage in dry years when water and food are short. In those years, they will attack developing heads in the stem or at the milky-dough stage, causing much more damage than if they attack just the hard grain for food.<sup>5</sup>

## 7.3 Soil insects

The majority of establishment pests are soil-dwelling insects. Soil insects can reduce plant establishment, plant populations, plant growth, and subsequent yield potential. Monitor for soil insects prior to planting.

Various cultivation systems and farm-management practices can directly influence the composition and abundance of pest species:

- Weedy fallows and volunteer plants encourage soil insect build-up.
- Insect numbers decline during a clean long fallow because of a lack of food.
- Retaining stubble can promote some soil insects but can reduce the amount of damage to germinating crops as the insects continue to feed on stubble.
- No-tillage encourages beneficial predatory insects and earthworms.
- Incorporating stubble promotes populations of black field earwig.
- False wireworms are found under all intensities of cultivation but decline if stubble levels are very low.<sup>6</sup>

### 7.3.1 Monitoring for soil insects

Soil insect control measures need to be applied at sowing. Soil insects, particularly damaging juvenile stages, cannot be controlled once the crop is planted. In high-risk situations (e.g. following a weedy fallow, high stubble, or history of soil insects), check for pests using the following techniques:

1. Soil sampling by spade
  - Take a number of spade samples (deep enough to take in the moist soil layer) from random locations across the field.
  - Hand-sort samples to determine type and number of soil insects.
2. Germinating grain bait technique—immediately following rain and before planting
  - Soak insecticide-free crop seed in water for at least 2 h to initiate germination.
  - Bury a small handful of the seed under 1 cm of soil at each corner of a 5 m by 5 m square at five widely spaced sites per 100 ha. If the soil is dry, place seed in moisture, or water the baits to ensure germination.
  - Mark the bait's position; large populations of soil insects can completely destroy them.
  - 5–10 days after placing baits, dig up the germinated seed and check for insects (Table 2).
  - Trials have shown no difference in the type of seed used when it comes to attracting soil-dwelling insects. However, use of the type of seed to be sown as a crop is likely to indicate the species of pests that could damage it.

### MORE INFORMATION

[K Charleston \(2014\) check for establishment pests before planting summer crops. The Beatsheet.](#)

[P Grundy \(2014\) Have you checked for establishment pests before planting? Australian Cotton conference.](#)

<sup>5</sup> Early pest of sorghum and maize. Pacific Seeds, <https://www.pacificseeds.com.au/agronomy-tools/summer-solutions.html>

<sup>6</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)

**Table 2:** Soil insect pest detection thresholds.

Soil insect	Scouting technique	Threshold for control
Black field earwig	Germinating grain baits	Average 5 per bait
False wireworm larvae	Germinating grain baits	Average 1 per bait
Wireworm larvae	Germinating grain baits	Average 1 per bait
Cutworms	Crop scouting after planting	–

Insecticide seed dressings protect the crop from most soil-dwelling insects during the seedling stage. However, monitoring at seedling stage is recommended because seed dressings may give only partial control of some insects such as earwigs, or when soil insects are abundant.

Paddocks with a history of poor strikes may have high levels of soil insects. Seed dusting helps deter insects. In-furrow spraying helps protect young roots and shoots. Press-wheels can reduce damage from false wireworm larvae and earwigs by encouraging plant emergence and firming the soil to reduce the insects' ability to move through it. Soil baiting may reduce damage by black field earwigs and crickets, which attack the tips of developing prop-roots (secondary roots). Shallow planting in warm, moist soil will encourage rapid crop emergence and growth, thus reducing the effect of insects.<sup>7</sup>

### 7.3.2 Black field earwig

Black field earwig (*Nala lividipes*) (Figure 1; compare with predatory earwig, Figure 2) is a sporadic and potentially major pest of maize.



**Figure 1:** Black earwigs.

Photo: QDAF

<sup>7</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)



**Figure 2:** *Predatory earwig attacking a Helicoverpa pupa. Note: predatory earwigs are usually larger than black earwigs and light brown in colour.*

Photo: QDAF

Black earwigs eat newly sown and germinating seed as well as the roots of crops, resulting in poor establishment.

Black earwigs feeding on secondary roots may cause plants to fall over as they get larger. Serious damage is usually confined to soils that retain moisture well, and earwigs prefer cultivated soils to undisturbed soil (no-till).

Monitor crops after planting until establishment. Dig and sieve soil to detect adults and nymphs prior to planting. Use germinating seed baits and control if >50 earwigs are present in 20 germinating seed baits. Grain baits containing insecticide applied at sowing offer best protection. Insecticide seed dressings provide some protection. In-furrow sprays are not effective in protecting against dense populations. Use press-wheels at sowing.<sup>8</sup>

### 7.3.3 True wireworm

True wireworm (*Agrypnus* sp.) larvae (Figure 3) bore into germinating seed and chew on seedling roots and shoots, resulting in reduced vigour, wilting or seedling death. Damage is worse when crop growth is retarded by dry, wet or cool conditions.

Wireworms generally favour moist areas. True wireworm larvae may also feed on *Helicoverpa* pupae. Use germinating seed baits or soil sampling to detect larvae prior to sowing. Monitor crops after sowing until establishment. One larva per germinating seed bait warrants control. Seed dressings, in-furrow sprays and granular insecticides offer some control.<sup>9</sup>

Wireworm numbers are not reduced by extreme dry weather; therefore, a long, dry period with no crop will not eliminate the problem.

<sup>8</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)

<sup>9</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)



**Figure 3:** *True wireworm.*

Photo: QDAF

### 7.3.4 False wireworm

False wireworm (*Gonocephalum* spp. and *Pterohelaeus* spp.) larvae (Figure 4) attack germinating seeds and seedling roots and shoots in spring, resulting in patchy stands. Damage is most common in early-planted crops with low crop residue. Adults may damage summer seedlings by chewing at or above ground level, and replanting may be required.

To detect, either hand-sift 10 soil samples (30 cm by 30 cm) or place 10 germinating seed baits throughout the paddock. One larva per sample (or germinating seed bait) warrants control.

Prepare ground for even and rapid germination. Use of press-wheels at planting provides some control. For larvae, use seed treatments or in-furrow sprays. For adults, use cracked grain baits.

Natural enemies provide little control. Infestations detected after crop emergence cannot be controlled.<sup>10</sup>



**Figure 4:** *False wireworm.*

Photo: QDAF

<sup>10</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)



### 7.3.5 Cutworm

Cutworm (*Agrotis* spp.) larvae (Figure 5) feed on leaves and stems of young plants, and they 'cut' down plants to eat the leaves. Partial damage to stems may cause the plant to wilt.

Larvae shelter in the soil during the day and curl into a C-shape when disturbed.

Cutworms are found in all soil types and often move into crops from adjoining fence lines, pastures or weedy fallows. Crop areas attacked by cutworms tend to be patchy, and the highest risk period is during summer and spring.

Emerging seedlings should be inspected twice per week, particularly in higher risk situations. Seedlings should be treated when there is a rapidly increasing area of infestation or proportion of crop damage (>10% seedling loss). Increasing infestations occur where larvae move from weeds or weedy field edges. Treat older plants if >90% of samples have one or more cutworms or when plants have  $\geq 75\%$  leaf tissue loss. Spot treatments (e.g. along field edges) may be successful. Spraying should be done late in the afternoon to increase the likelihood of contact with feeding caterpillars (dusk–night).

Keep fallows clean and eliminate weeds from paddock perimeters at least 1 month before planting. Severe damage to emerging crop can occur when large larvae are forced to move from weed hosts into the crop following spraying of the weeds. Cutworms are attacked by a range of natural enemies such as parasitoids, predators and diseases.<sup>11</sup>

Cutworms appear in a number of paddocks each year and they are not controlled by Cruiser® (a.i. thiamethoxam) and Gaucho® (imidacloprid). In-furrow applications of chlorpyrifos may be successful if cutworms are present; chlorpyrifos has very short residual control, so if eggs are laid after the planting operation, limited control can be expected.

Cutworms are very difficult to find in dark, moist clay soils because they are the same colour. In row crops planted with a twin disc, they are often found at the base of the seedling in the seed trench. Damage to seedlings is often the first sign of their presence; typically, cutworms lop off the seedling at ground level at night and pull the green material into the ground for safe consumption. v

Fields close to pasture, weedy road-sides or fields with heavy weed pressure are usually at risk. Some species of cutworm lay their eggs under the leaves of weeds such as wild turnip and milk thistle. Chemical control typically revolves around surface sprays of chlorpyrifos applied late in the afternoon or at night. Control is usually adequate, but under high pressure, a second application is often needed and replanting with in-furrow sprays has occurred. Please consult your consultant before application of any chemical.<sup>12</sup>

#### MORE INFORMATION

[Australian Pesticides and Veterinary Medicines Authority.](#)

<sup>11</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)

<sup>12</sup> Early pest of sorghum and maize. Pacific Seeds, <https://www.pacificseeds.com.au/agronomy-tools/summer-solutions.html>





**Figure 5:** Cutworm.

Photo: QDAF

### 7.3.6 Scarab larvae

These beetle larvae (Coleoptera: Scarabaeidae) (Figure 6) feed on roots, causing loss of vigour and lodging. Adults may feed on leaves.<sup>13</sup>

Scarab damage to establishing crops has been reported from the Darling Downs to Northern NSW. The highest number of reports of scarab infestation, and crop loss caused by scarabs, has been from the eastern Downs, but this may be a result of a higher level of awareness in these areas. Sorghum is the crop most frequently reported with crop loss, but crop loss has also been confirmed in sunflower, maize, mungbean, and wheat.

Researchers have collected at least 4 species of larvae (known as whitegrubs) from fields and believe the most common species is *Othnonius batseii*, the black soil scarab.

Scarabs generally have a 1–2 year lifecycle, which can be longer if the larvae do not have suitable growing conditions (too dry, inadequate food source). This means larvae can be present in fields 12 months of the year. The larvae feed on roots, impacting on plant growth and ability to tolerate moisture stress. The impact of scarab feeding is visible as slowed crop growth, plant death (often in patches), delayed maturity and lodging.<sup>14</sup>

#### Damaging densities

Densities above 15 larvae per m<sup>2</sup> (to 15 cm depth) are associated with significant crop loss. This tentative threshold is influenced by a number of conditions including crop, scarab species, soil moisture, cultivation, sowing equipment, use of seed dressings and in-furrow treatments. Densities below 15 per m<sup>2</sup>, seed dressings and in-furrow treatments may provide some protection. At higher densities, particularly those above 25 larvae per m<sup>2</sup>, observations suggest that even at-sowing treatments do not prevent significant crop loss.

The results from replicated trials showed that cultivation, either with disc or chisel plough, reduced larvae numbers significantly. In these trials the cultivation resulted in a full disturbance of the soil surface and correspondingly high reductions in soil

<sup>13</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)

<sup>14</sup> M Miles, A Quade, R Lloyd, P Grundy (2016) Recent insect pest management research findings and the application of results in the field. GRDC Update Papers 26 February 2016, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Recent-insect-pest-management-research-findings-and-the-application-of-results-in-the-field>

**i MORE INFORMATION**

[Scarab grubs in northern tableland pastures](#)

[Emerging insect threats in northern grain crops](#)

moisture. Researchers monitored the impact of several commercial fields where the growers have cultivated infested patches in the field. Results have shown similarly large decreases in the larval populations.

The impact of cultivation on soil moisture is a major impediment to the potential uptake of cultivation to manage high density infestations. However, it may be possible to be more targeted with cultivation and achieve the same outcome. Examination of the distribution of larvae across the plant row and inter-row shows a concentration of larvae on the plant row in the majority of fields. This pattern of distribution opens up the possibility of more targeted tillage, with reduced disturbance.

Once a crop is planted, there are no insecticide options for controlling scarab larvae. Consequently, any attempt to mitigate the impact of larvae either by killing them or repelling them from the root zone must be implemented at sowing.<sup>15</sup>

Damage is often patchy, and there are no effective controls, although a *Metarhizium* fungus and nematodes are reported occasionally to cause high larval mortality. Avoid sowing new ground with maize after pasture in areas that have a known history of whitegrubs.<sup>16</sup>



**Figure 6:** *Whitegrub.*

Photo: QDAF

## 7.4 Pests of the vegetative stage

### 7.4.1 Maize leafhoppers

Maize leafhoppers (*Cicadulina bimaculata*) (Figure 7) are most common during late summer. They suck sap, and high populations (>15 individuals/plant) can transmit wallaby ear mycoplasma. Mycoplasma-infected plants are dark green with thickened veins on the underside of leaves (Figure 8).

Hybrid varieties offer some resistance. Inspect crops weekly during the vegetative stage, and control if >10 leafhoppers/plant and wallaby ear symptoms are present.<sup>17</sup>

<sup>15</sup> M Miles, A Quade, R Lloyd, P Grundy (2016) Recent insect pest management research findings and the application of results in the field. GRDC Update Papers 26 February 2016, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Recent-insect-pest-management-research-findings-and-the-application-of-results-in-the-field>

<sup>16</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)

<sup>17</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)



**Figure 7:** *Maize leafhoppers.*

Photo: QDAF



**Figure 8:** *Mycoplasma-infected plants are dark green with thickened veins on the underside of leaves.*

Photo: QDAF

### 7.4.2 Maize thrips

Maize thrips (*Frankliniella williamsi*) attack seedling and vegetative growth stages. Thrips in the whorl can stop the growth of small plants.



Infected plants may have yellow or silvery patches on the leaves and a desiccated or wilted appearance. Damage is more severe if plants are stressed by drought or waterlogging and growth is slowed, compounding the damage. Inspect weekly during seedling and vegetative stages, and control if thrips are found in the whorl combined with yellowing of the throat or necrotic stripes on young leaves. Seed treatments can provide translocative–translaminar activity on sucking insects during the seedling stage.

Maize leafhoppers and maize thrips are widespread but irregular in Queensland, and can rapidly re-infest crops after spraying, meaning more than one spray may be required.<sup>18</sup>

### 7.4.3 Corn aphid

Corn aphid (*Rhopalosiphum maidis*; Figure 9) is the most common aphid species on maize and can affect any crop stage. Adults and nymphs suck sap and produce honeydew. High numbers can cause plants to turn yellow and appear unthrifty. Yield loss may occur on water-stressed plants.

Damage is generally too low to warrant control. Chemical control options are generally not cost-effective and the insecticides that control aphids may negatively affect natural enemies.

Inspect at weekly intervals. Predators of aphids include ladybird larvae, damsel bugs, bigeyed bugs, larvae of green lacewings and larvae of hoverflies. Wasp parasitoids mummify and kill aphids.



**Figure 9:** Corn aphid.

Photo: QDAF

Aphid numbers have been high in barley and canary crops. These are predominately oat aphids, which can be found at the base of the plant where they are well protected; oat aphids do not usually infest sorghum and maize in Australia but have

<sup>18</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)





been a pest of maize in the USA. Corn aphids are present in the upper leaves and the whorl of the barley and have begun to migrate to early-planted maize crops.

Both Cruiser® and Gaucho® give good suppression for 2–3 weeks, even though control of aphids is not listed on either seed treatment label. Corn aphid very rarely requires control because the number of disruptive sprays has been drastically reduced in the farming system. Aphid numbers can become very high in moisture-stressed crops, and it is tempting to spray in these situations; however, if left alone, beneficial insects usually control these sticky pests. Spraying disruptive chemicals in the vegetative stage can cause greater problems later, with aphids and *Helicoverpa* infesting the corn silks and tassels in particular.<sup>19</sup>

Build-up of aphids later in the crop can transmit viruses, smothering developing cob sheaths and causing sticky residue over leaves, cobs. Rarely does it affect yield unless transmitting particular viruses impacting on maize.

#### 7.4.4 Podsucking or shield bugs

These are:

- green vegetable bugs (GVB) (*Nezara viridula*) (Figure 10)
- redbanded shield bug (*Piezodorus hybneri*) (Figure 11).

They are widespread but irregular pests of maize during summer. Adults and nymphs feed by piercing and sucking on developing cobs, and may severely deform cobs.

Although chemical control may be cost-effective, there are no threshold current levels for GVB in maize.<sup>20</sup> Large numbers can cause discoloured or aborted kernels in the cob, noticeable at harvest. This may affect quality for grit markets.



**Figure 10:** Green vegetable bugs, adults and nymphs.

Photo: QDAF

<sup>19</sup> Early pest of sorghum and maize. Pacific Seeds, <https://www.pacificseeds.com.au/agronomy-tools/summer-solutions.html>

<sup>20</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)





**Figure 11:** *Redbanded shield bug.*

Photo: QDAF

### 7.4.5 Locusts

Locusts (Figure 12) are sporadic and potentially major pests of maize. Adults and hoppers chew irregular pieces from leaves and stems and can cause complete defoliation overnight at high populations. Species found in maize include Australian plague locusts, migratory locusts, and spur-throated locusts.

The Australian Plague Locust Commission provides details of hopper migrations.<sup>21</sup>



**Figure 12:** *Locust.*

Photo: QDAF

<sup>21</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)

### Whitefringed weevil

Whitefringed weevil (*Naupactus leucoloma*) larvae chew into lateral roots, causing death and reduced vigour. Infestations are usually patchy. Mass emergence of adults occurs after rain in November–January, and damage is often worse when two host crops (e.g. maize, peanuts, chickpea, lucerne) are grown consecutively.<sup>22</sup>

### 7.4.6 Redshouldered leaf beetle

Restricted to coastal areas, redshouldered leaf beetle (*Monolepta australis*) (Figure 13) and can infest at any stage of crop growth.

Swarms of adult beetles move into a crop and feed on foliage, tassels, silks and the husk at the top of the cob. Injury to silks may reduce seedset. Feeding exposes the cobs to other insects and diseases. Infestations tend to be patchy, so thorough weekly checking is required. Control is warranted if 95% of plants in an area are infested and 70% of flag leaves are eaten. Chemical control is cost-effective at high rates of infestation.<sup>23</sup>



**Figure 13:** Redshouldered leaf beetle.

Photo: QDAF

### 7.4.7 Swarming leaf beetles

Swarming leaf beetles (*Rhyparida* spp.) are a minor, irregular pest of maize in Queensland, more frequent in the north. Leaf beetles are likely to be present during the seedling stage. Larvae feed on roots, causing up to 40% seedling death. There are no current recommended methods of monitoring, and economic injury levels have not been established. Avoid planting maize immediately after grass pasture.<sup>24</sup>

### 7.4.8 Armyworms

These are:

- common armyworm (*Leucania convecta*)

<sup>22</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)

<sup>23</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)

<sup>24</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)

- day-feeding armyworm (*Spodoptera exempta*).

Armyworms (Figure 14) can occur in large numbers, especially when good rain follows a dry period. During the day, the common armyworm shelters in the throats of plants or in the soil and emerges after sunset to feed. Outbreaks of day-feeding armyworm typically occur from late December to March, and larvae are active during the day. Young plants may be defoliated or killed. Older plants can outgrow damage but yield may be reduced.

Signs of damage include chewed leaf margins and faecal pellets at the base of young plants or in the throats of older plants.

Monitor during seedling and vegetative stages. Egg lays are often associated with heavy rainfall, so check for larvae several weeks after rainfall events. Look for larvae under clods of soil, under vegetation and at the base of plants. As a guide, control is warranted if, out of a count of 30 plants, 27 are infested and >21 have at least 75% flag-leaf loss.

Many chemicals will control armyworms but their effectiveness often depends on good coverage, and control may be more difficult in high-yielding, thick canopy crops, particularly when larvae are resting under leaf litter at the base of plants. Because larvae are most active at night, spraying in the afternoon or evening may produce the best results.

Armyworm larvae are attacked by a number of parasitoids, which may assist in reducing the intensity of outbreaks, although they are unlikely to give timely control if armyworm numbers are high. Predators include green carabid beetles, predatory shield bugs and perhaps common brown earwigs. Viral and fungal diseases are recorded as causing mortality of armyworms.<sup>25</sup>

Common armyworm can cause severe damage to winter cereals and emerging summer crops. Generally, the moths lay in barley crops in September and October. The larvae prefer lush crops that provide good cover and protection. If larvae have not finished development as the barley is haying-off, they can migrate to nearby fields of summer crops. Bare patches on the edges of fields adjoining barley are a good indicator that armyworm may be present. Low numbers in barley can cause high levels of damage in young summer crops. In dry years, armyworm damage can be mistaken for dry patches in the field.<sup>26</sup>



**Figure 14:** Armyworm.

Photo: QDAF

<sup>25</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)

<sup>26</sup> Early pest of sorghum and maize. Pacific Seeds, <https://www.pacificseeds.com.au/agronomy-tools/summer-solutions.html>

## 7.5 Silking–tasseling-stage pests

### 7.5.1 Corn earworm

Corn earworm (*Helicoverpa armigera*) (Figure 15) occurs regularly in maize, but only occasionally does it warrant control. Female moths lay eggs on the stem, leaves (both sides), tassels, silks and husks on the upper two-thirds of plants. Caterpillars hatching prior to silking cause little damage to tassels but may cause damage when migrating to cobs.

Larvae from eggs laid on silks or husks may cause significant damage. However, the most damaging scenario is when large larvae that have developed in the vegetative crop move to the silks and sever them as they feed. Silk damage reduces pollination and grain-set. Feeding damage also occurs on the top 1–3 cm of the cob and may result in the presence of mycotoxins. Damage traditionally occurs on the top 1–3 cm of the cob, but there are increasing incidences of larvae drilling into the side of the cob. This may be due to new varieties having softer husk cover.

Leaf damage can indicate the presence of *Helicoverpa* larvae in vegetative crops. Armyworm damage is similar. Parallel rows of holes are signs of feeding on unopened leaves. *Helicoverpa* are not usually considered economic to control, except in high-value seed maize. Occasionally, grain maize crops are severely damaged by *Helicoverpa* and warrant treatment. Control of *Helicoverpa* at this stage has become a regular occurrence on the Liverpool Plains. Along with many other summer crops, maize crops at silking and tasseling have become a significant attraction for *Helicoverpa armigera*.

Chemical control should target small caterpillars (up to 7 mm) and should be directed at tassels and emerging silks. Nucleopolyhedrovirus (NPV) is an option for *Helicoverpa* control with the benefit of preserving beneficial insects that will contribute to ongoing suppression of *Helicoverpa* and other pests.

Maize varieties with husks extending 50–80 mm beyond the top of the cob and closing tightly around the silks restrict the entry of larvae into the cob. Watering during dry weather prevents the husks from loosening.

Maize crops often have high levels of beneficial insects (predators and parasitoids) and these may be harmed by insecticide applications. The combined action of natural enemies (including predators of eggs, larvae and pupae, parasites of eggs and larvae, and caterpillar diseases) can have a significant impact. Cultivation to a depth of 100 mm destroys overwintering pupae.

Moderate to high levels of egg parasitism by *Trichogramma* are common. Typically, the level of parasitism increases in later crops, and can be as high as 90%.<sup>27</sup> It may be economic to invest in a *Trichogramma* release during the late vegetative stage.

27 K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)





**Figure 15:** Corn earworm.

Photo: QDAF

## 7.6 Pests of the grainfill stage

### 7.6.1 Two-spotted mite

Two-spotted mite (*Tetranychus urticae*) is a widespread but irregular pest of maize during seed-fill to maturity. Mites are usually present towards the end of the crop cycle during late summer–autumn and are favoured by hot, dry weather. Adults and nymphs pierce and suck on lower leaf surfaces, causing silverying on the upper leaf surfaces. Fine webbing on the lower leaf surface indicates their presence, and heavy infestations will result in leaf desiccation, leaf drop and yield loss. A hand lens can be used to examine lower leaves for mites. Initial infestations can be patchy. No thresholds are available for mites in maize and control is not cost-effective. The use of broad-spectrum insecticides is associated with outbreaks of mites. Broad-spectrum insecticides disrupt the activity of beneficial insects (particularly thrips) that suppress mite populations.<sup>28</sup> Spider mites are very active on Liverpool Plains and they have traditionally caused significant damage.

Control is warranted. There is a permit for abamectin use in field maize for control of mites. The region tends to use it every year in some districts.

### 7.6.2 Yellow peach moth

Yellow peach moth (*Conogethes punctiferalis*) is a minor and irregular pest of maize. Eggs are laid during silking. Larvae tunnel into stems or cobs, producing masses of webbing and excreta at the tunnel entrance. No chemical controls are available. The larval habit of mining into stems and cobs makes insecticide application ineffective, because larvae cannot be reached within tunnels.<sup>29</sup>

### MORE INFORMATION

[K Charleston \(2014\) Armyworms defoliating sorghum, millet and corn on the Downs. The Beatsheet.](#)

<sup>28</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)

<sup>29</sup> K Charleston (2013) Maize insect pest management. Northern grains region. Department of Agriculture, Fisheries and Forestry Queensland, [http://ipmworkshops.com.au/wp-content/uploads/Maize\\_IPM-Workshops\\_north-March2013.pdf](http://ipmworkshops.com.au/wp-content/uploads/Maize_IPM-Workshops_north-March2013.pdf)



**i MORE INFORMATION**

[K Owen \*et al.\* Root lesion nematode—Queensland. Fact Sheet. Soil Quality Pty Ltd.](#)

**i MORE INFORMATION**

<https://sites.google.com/site/crownanalyticalservices/>

[PreDicta B. SARDI Diagnostic Services.](#)

[Root-lesion nematodes—management of root-lesion nematodes in the northern grain region. QPIF.](#)

**i MORE INFORMATION**

[GRDC Tips and Tactics: Root-Lesion Nematodes](#)

# Nematode management

Root-lesion nematodes (RLN) are microscopic, thread-like animals that live in soil and plant roots. Plant roots that are damaged by nematodes are inefficient at taking up water and nutrients, causing up to 65% yield loss in intolerant wheat varieties. *Pratylenchus thornei* is found in ~70% of fields in the northern grain region.<sup>1</sup>

Resistance and susceptibility of crops can differ for each RLN species, and maize is moderately susceptible to both *P. thornei* and the secondary species, *P. neglectus*.<sup>2</sup>

Management of the *P. thornei* requires:

- growing tolerant wheat varieties so that yields are maximised
- rotating with two or more successive resistant crops such as sorghum so that populations of the nematodes decrease.<sup>3</sup>

In the northern grain region, the predominant RLN, *P. thornei*, costs the wheat industry A\$38 million annually.<sup>4</sup>

## 8.1 Nematode testing of soil

It is important to have paddocks diagnosed for plant parasitic nematodes so that optimal management strategies can be implemented. Testing your farm will tell you:

- if nematodes are present in your fields and at what density
- which species are present.

It is important to know which species are present because some crop-management options are species-specific. If a particular species is present in high numbers, immediate decisions must be made to avoid losses in the next crop to be grown. With low numbers, it is important to take decisions to safeguard future crops. Learning that a paddock is free of these nematodes is valuable information because steps may be taken to avoid future contamination of that field.<sup>5</sup>

Testing of soil samples taken either before a crop is sown or while the crop is in the ground provides valuable information.

## 8.2 Effects of cropping history on nematode status

RLN numbers build up steadily under susceptible crops and cause decreasing yields over several years. The amount of damage caused will depend on:

- the numbers of nematodes in the soil at sowing
- the tolerance of the variety of the crop being grown
- the environmental conditions.

Generally, a population density of 2000 RLN/kg soil anywhere in the soil profile has the potential to reduce the grain yield of intolerant wheat varieties.

<sup>1</sup> K Owen, T Clewett, J Thompson (2014) Latest nematode summer and winter crop rotation results. GRDC Update Papers, 7 March 2014, <http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Latest-nematode-summer-and-winter-crop-rotation-results>

<sup>2</sup> K Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet, <http://www.soilquality.org.au/factsheets/root-lesion-nematode-in-queensland>

<sup>3</sup> K Owen, T Clewett, J Thompson (2014) Latest nematode summer and winter crop rotation results. GRDC Update Papers, 7 March 2014, <http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Latest-nematode-summer-and-winter-crop-rotation-results>

<sup>4</sup> GM Murray, JP Brennan (2009) The current and potential costs from diseases of wheat in Australia. GRDC Report, <https://www.grdc.com.au/media/B4063ED6F63C4A968B3D7601E9E3FA38.pdf>

<sup>5</sup> QDAF (2009) Root-lesion nematodes—management of root-lesion nematodes in the northern grain region. Queensland Government, [http://www.daf.qld.gov.au/\\_data/assets/pdf\\_file/0010/58870/Root-Lesion-Nematode-Brochure.pdf](http://www.daf.qld.gov.au/_data/assets/pdf_file/0010/58870/Root-Lesion-Nematode-Brochure.pdf)

A tolerant crop yields well when high populations of RLN are present (the opposite is intolerance). A resistant crop does not allow RLN to reproduce and increase in number (the opposite is susceptibility).

Growing resistant crops is the main tool for managing nematodes. Information on the responses of crop varieties to RLN is regularly updated in grower and Department of Agriculture, Fisheries and Forestry Queensland planting guides. Note that crops and varieties have different levels of tolerance and resistance to *P. thornei* and *P. neglectus* (see Table 1).<sup>6</sup>

**Table 1: Susceptibility and resistance of various crops to root-lesion nematodes.**<sup>7</sup>

RLN species	Susceptible	Intermediate	Resistant
<i>P. thornei</i>	Wheat, chickpea, faba bean, barley, mungbean, navy bean, soybean, cowpea	Canola, mustard, triticale, durum wheat, maize, sunflower	Canary seed, lablab, linseed, oats, sorghum, millet, cotton, pigeon pea
<i>P. neglectus</i>	Wheat, canola, chickpea, mustard, sorghum (grain), sorghum (forage)	Barley, oat, canary seed, durum wheat, maize, navy bean	Linseed, field pea, faba bean, triticale, mungbean, soybean

### 8.3 Using rotations including maize to manage nematodes

Maize hybrids range from susceptible to moderately resistant to *P. thornei*. Although maize may not suffer yield loss due to *P. thornei*, some hybrids of maize will cause populations of the nematode to build up and nematodes will remain in high numbers to attack the next crop. Rotations will differ depending on whether you have *P. thornei*, *P. neglectus* or both species. Very high nematode populations are reduced by increasing the number of resistant crops grown consecutively in rotations. It may take two or more resistant crops to reduce damaging populations. When RLN are present, tolerant crops will produce higher yields than intolerant crops. However not all tolerant crops are resistant.<sup>8</sup>

#### Key points

- Test soil to monitor population changes in rotations and to determine RLN species and population density.
- Avoid consecutive susceptible crops in rotations to limit the build-up of RLN populations.
- RLN can multiply in cereal and legume crops and each nematode species can build up on different crops.
- Choose wheat varieties with tolerance to maximise yields when RLN are present.
- Choose rotation crops with high resistance ratings, so that fewer nematodes remain in the soil to infect subsequent crops.
- Two or more consecutive resistant crops may be needed to reduce damaging populations.<sup>9</sup>

For more information on the effect of summer crop rotations on RLN in winter crops, see *GRDC GrowNotes Wheat, Section 8. Nematode control*.

#### MORE INFORMATION

[Summer cropping options to manage root lesion nematodes](#)

<sup>6</sup> QDAF (2009) Root-lesion nematodes—management of root-lesion nematodes in the northern grain region. Queensland Government, [http://www.daf.qld.gov.au/\\_data/assets/pdf\\_file/0010/58870/Root-Lesion-Nematode-Brochure.pdf](http://www.daf.qld.gov.au/_data/assets/pdf_file/0010/58870/Root-Lesion-Nematode-Brochure.pdf)

<sup>7</sup> KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

<sup>8</sup> K Owen, T Clewett, J Thompson (2016) Summer cropping options to manage root lesion nematodes. GRDC Update Papers 21 July 2016, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Summer-cropping-options-to-manage-root-lesion-nematodes>

<sup>9</sup> GRDC (2015) Root-lesion nematodes. Northern Region. GRDC Tips and Tactics, <http://www.grdc.com.au/TT-RootLesionNematodes>

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[Maize disorders: the ute guide.](#)  
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[Growth potential. Corn growers' workshop. Pioneer Hi-Bred.](#)

[A Robertson \*et al.\* Corn diseases.](#)  
[Iowa State University.](#)

[Corn field guide. 2nd edn. Iowa State University.](#)

 MORE INFORMATION

[Where did the low levels of Fusarium head blight come from in 2016 and what does it mean](#)

## Diseases

Diseases affecting maize grown in Australia include cob rots, stalk and root rots, viruses, smuts, leaf blights and leaf rusts.

The incidence and severity of disease outbreaks depend on several factors including management (water, nutrition and crop hygiene), varietal genetics and hybrid vigour, location, planting date, seasonal extremes, infestation by insects, cultural practices, populations and husk cover giving cob protection.

Most of the hybrids released in Australia have an acceptable level of disease resistance.<sup>1</sup> Many diseases in maize can be overcome by selecting resistant hybrids. Additionally, good farm hygiene, including washing down equipment and controlling weeds and volunteers, can minimise disease spread from crop to crop and from season to season. Diseases are important to maize production not only because of their potential to reduce yield, but also because the marketing of grain can be severely restricted by the mere presence of disease, adding further to the need to choose hybrids carefully. For more information on resistance in hybrids, see [GrowNotes Maize Section 2. Pre-planting.](#)<sup>2</sup>

Select hybrids that have resistance to diseases prevalent in your area. On the north coast of NSW, hybrids need good resistance to turcica leaf blight (also known as northern leaf blight, caused by *Exserohilum turcica*) and Maize dwarf mosaic virus (MDMV). In many areas, Fusarium kernel rot (caused by *Fusarium* spp.) has resulted in significant yield losses and quality issues in grain samples. It can also be a host for Fusarium head blights in winter cereals.

Commercial hybrids are relatively tolerant to boil smut (caused by the fungus *Ustilago zeae*), and to date the disease has not caused significant yield losses, except where crops have been moisture stressed just prior to silking; however, the pathogen is air-borne and it is difficult to breed resistance to boil smut. In coastal districts, select hybrids with tight husk cover to help prevent weevil and *Helicoverpa* damage and also to significantly reduce cob rots and weather damage. In inland regions, loose husk cover is often considered an advantage because it encourages rapid dry down.<sup>3</sup>

### 9.1 Diseases of a developing and mature maize plant

Since the 1930s when maize was converted from an open pollinated species to a hybrid, disease resistance has been a high priority for breeders around the world. Most of the maize diseases in Australia are influenced by seasonal conditions causing stress on the plant, such as very hot spells during grainfill, continued cloudy weather, build-up of virus-spreading insects and high humidity.

As with nutrient deficiencies, diseases are often hard to positively identify in the field. Samples may need to be sent to a plant pathologist for identification, particularly for the cob and stalk rots, and viruses.

Nearly all cases of stalk and cob rots can be traced back to a period of stress at a crucial stage of development, for example, a vital watering being delayed by a couple of days.

- 1 Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>
- 2 N Moore, L Serafin, L Jenkins (2014) Summer crop production guide. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>
- 3 N Moore, L Serafin, L Jenkins (2014) Summer crop production guide. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>



### 9.1.1 Seed rots and seedling blights

Germinating maize seed may be attacked by a number of soil-borne or seed-borne fungi that cause seed rots and seedling blights. These diseases are prevalent in poorly drained, excessively compacted or cold (<10–13°C) and wet soils. Disease severity is affected by planting depth, soil type, age and quality of seed, mechanical injury to the pericarp and genetic resistance to infection. Sweet corn is more susceptible than field maize. The main fungi involved are: *Pythium* spp., the rotted area may be dark with sporangia and oospores in the tissues; *Diplodia* spp., whitish-grey; *Fusarium* spp., white to pink; and *Penicillium* spp., bluish mycelium and masses of spores.

### 9.1.2 Stalk and root rot diseases

Stalk rots are diseases that are most commonly expressed as plants reach maturity. Maize stalk rot (Figure 1) tends to be a complex of several disease-causing fungi and sometimes bacteria; seldom will only one casual organism be isolated and identified. Plants with rotted stalks almost always have rotted roots as well. Usually, the same casual organisms are involved. Visual identification is very difficult; typically, wilting is the first sign of stalk rot in a field. In a few days, leaves turn a ‘frosted’ grey, ears droop and the outer rind of the lower stalk turns brown. Fields where stalk rot is developing should be harvested early to reduce grain losses.<sup>4</sup>



**Figure 1:** Bacterial stalk rot.

Photo: Pacific Seeds

<sup>4</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

### **Fusarium stalk rot (caused by *Fusarium verticillioides* [*Gibberella fujikuroi*] and other *Fusarium* species)**

Although Fusarium stalk rot is common in many of the maize-growing areas of Australia, it tends to be more severe in warm, dry regions. On the Atherton Tablelands, it often occurs in the first maize crop after a lengthy pasture phase. *Fusarium* species and other fungi can also cause seedling blight but this is uncommon because of improved seed production and handling, and planting techniques.

Infected seedlings are usually stunted and have pale green or purple leaves and poor roots. Symptoms of Fusarium stalk rot in mature plants are difficult to distinguish from those of other stalk rots, but the internal tissues of affected stalks are usually reddish-brown and rotted. The discoloration may also be seen on the surface of the stalks near nodes. Stalks are weak and lodge easily.

Good agricultural practices, including crop rotation, correct plant densities and the minimisation of stress, assist in reducing Fusarium stalk rot. Resistant hybrids should be used to manage this disease.<sup>5</sup>

### **Gibberella stalk rot (caused by *Gibberella zeae*; *Fusarium graminearum*)**

This fungal disease is favoured by moist conditions. It is more common on the Atherton Tablelands and in coastal and inland northern NSW, where it can cause serious yield loss. The disease is much less serious in other regions, including southern Queensland. It is common where maize monoculture is practiced.

The surfaces of infected stalks are often reddish brown, particularly around the nodes, and the tissues internally are red-pink. Stalks are weak and break easily, resulting in lodging and plant death. Later in the season, small, round, bluish black fruiting bodies may be found around the nodes of dead stalks.

Similar to the *Fusarium* species that cause Fusarium stalk rot, *F. graminearum* survives in infected residues and can systemically infect plants. The fungus causes head blight of winter cereals and has been a problem in some years on the Liverpool Plains of NSW in maize–wheat rotations.

Use crop rotation (avoiding maize–winter cereal rotations), good agronomic practices to minimise stress, and/or resistant maize hybrids to combat this disease.<sup>6</sup> Decomposing maize residue significantly reduces the survival and spread of the pathogen to surrounding cereals.

## **9.1.3 Ear and kernel rots**

These rots can affect ears or kernels, reducing test weight and grain quality. Some rots are responsible for development of mycotoxins that may contaminate grain. Rotting observed in the field is often due to a complex of casual organisms, not just one. Most ear rots are favoured by late season humidity.

Infections are increased by cob damage from birds or insects and by stalk lodging, which allows ears to contact the soil.

Growth stages during which symptoms generally appear are:

- stage I, emergence to knee high
- stage II, from knee high to tasselling
- stage III, from tasselling to maturity.

5 QDAF (2012) Diseases affecting maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/diseases>

6 QDAF (2012) Diseases affecting maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/diseases>



### **Fusarium cob rot or ear rot (*Fusarium verticillioides* and other *Fusarium* species)**

Fusarium cob rot is favoured by warm, dry weather at or after flowering and can occur in all maize-growing areas of Australia. *Fusarium verticillioides*, the main pathogen, produces the mycotoxin fumonisin, which is toxic to livestock, particularly horses.

Individual or groups of infected kernels are scattered at random on the cobs, but in severe cases, the entire cob can be affected. Whitish pink lavender fungal growth occurs on and between the kernels, often at the tip of the cob as the result of insect damage. Individual kernels may also exhibit a 'starburst' symptom, whereby white streaks radiate from the point of attachment.

The *Fusarium* species overwinter in infected residues. During the growing season, airborne spores infect the silks at flowering. They are also known to be systemic in maize plants and grow rapidly when plants are stressed.

The practices outlined above for Fusarium stalk rot, as well as the management of insect pests and proper storage of kernels, reduce the risks of mycotoxin contamination. Use resistant hybrids where available.<sup>7</sup>

### **Gibberella cob rot, ear rot or pink ear rot (caused by *Gibberella zeae*; *Fusarium graminearum*)**

Gibberella cob rot is favoured by cool, moist conditions at flowering. Therefore, like the stalk rot phase, it is more common in wetter, cooler growing regions. Several mycotoxins are produced by *F. graminearum*, including zearalenone and the trichothecene group, which are harmful to a wide range of livestock, especially pigs. Maize monoculture, maize–winter cereal rotations and plant stress during grainfill are factors in the disease.

The most common symptom is a reddish pink or whitish pink fungal growth that appears at the tip of the cob and grows down. Husks tend to bind to the kernels and there may be black fruiting bodies on external husk leaves. Infection occurs from windborne spores, which grow down the silks at flowering.

The use of good agronomic practices, resistant hybrids, prompt harvesting and proper storage minimises the risk.<sup>8</sup>

### **Diplodia cob rot or ear rot (caused by *Diplodia* spp.)**

Most of the species that cause Diplodia cob rot are also capable of causing seedling death, stalk rot, and/or leaf spot; however, cob rot is the most significant disease. Wet weather favours infection of cobs and leaves.

If infection occurs after flowering, the husks covering the cobs are bleached. Cobs are usually shrunken, lighter than normal and covered in a white-grey fungal growth. Black fruiting bodies (smaller than the fruiting bodies of *Gibberella* spp.) develop in the husks and cobs towards the end of the growing season.

*Diplodia* species survive in infected residues, and spores produced in fruiting bodies are splashed on the silk, which remain susceptible to infection as they are drying.

The only known management options to hasten residue breakdown are crop rotation and agronomic practices.<sup>9</sup>

7 QDAF (2012) Diseases affecting maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/diseases>

8 QDAF (2012) Diseases affecting maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/diseases>

9 QDAF (2012) Diseases affecting maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/diseases>

## 9.1.4 Blights

### Turcica leaf blight or turcicum leaf blight (caused by *Exserohilum turcicum*)

Turcica leaf blight can occur in all growing regions. It is favoured by warm weather when leaves are wet for extended periods from dew or rainfall. Under weather conditions that are conducive, it can cause significant yield losses in susceptible hybrids. It is of particular concern in areas experiencing high rainfall, humidity and temperatures, such as coastal NSW, where the disease is present most seasons. Specifically, 14 h (non-consecutive) of temperatures  $\geq 20^{\circ}\text{C}$  and 1 h of leaf wetness are necessary for infection to occur. Dew conditions also promote disease growth. Late-sown crops are also susceptible to infection. Inoculum overwinters on stubble and maize volunteers, as well as sorghum, and this should be accounted for in rotation plans. Inoculum is dispersed by wind and rain splash.

Long, spindle-shaped, greyish green to tan, water-soaked spots (up to 150 mm long and usually  $< 20$  mm wide) develop on leaves and later turn light purplish brown or grey. As the lesions dry out they become black in the centre as masses of spores are produced by the fungus. The lesions are not confined by the leaf veins. As the disease progresses the lesions may coalesce, causing large areas of leaf to wither and die. After flowering, the disease can develop rapidly, resulting in blighting of infected leaves.

The fungus survives on volunteers and maize residues, and its spores are spread over long distances by wind.

Leaf blight can have deleterious effects on crop yield. Where significant leaf tissue is destroyed, only small cobs are produced.

Resistant varieties, correct sowing time, crop rotation, regular monitoring, and removal of stubble and hosts will reduce risk of disease. Do not practice maize monoculture. Eliminate volunteer maize. Early planting can reduce the risk of this disease. Chemical control options are also available, in which leaf coverage is essential, because untreated leaf area is susceptible to blight.<sup>10</sup>

### Maydis leaf blight (caused by *Bipolaris maydis*)

Infection and disease development are favoured by warm, showery, humid weather. Although it can occur in all maize growing areas, maydis leaf blight is more common in the tropics.

Symptoms can vary depending on the hybrid. Spots range from tan, elongated spots up to 40 mm long and 6 mm wide with parallel sides, to tan, spindle-shaped or elliptical spots up to 25 mm long and 12 mm wide. Spots often have dark red-brown margins and/or a narrow yellow halo. This fungus can be seedborne and cause seedling rot.

The fungus survives on diseased residues, volunteer maize and grasses.

Resistant hybrids should be planted to combat this disease.<sup>11</sup>

## 9.2 Rusts

Although rust occurs across NSW and is present in most seasons, severe outbreaks are uncommon, and resultant economic loss is low.

Rust appears on leaves initially as small reddish brown pustules to 2 mm long in scattered groups, usually from tasselling onwards. Pustules will lighten with maturity as surrounding leaf tissue dies. With severe infection, leaves will wither and die. Seedling infection may also occur, leading to stunting and defoliation.

<sup>10</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

<sup>11</sup> QDAF (2012) Diseases affecting maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/diseases>

Humid conditions coupled with mild temperatures favour disease development in susceptible hybrids. Late plantings tend to be at greatest risk. Maize volunteers, stubble and some winter crops host rust; however, inoculum is also wind dispersed.

Appropriate varietal selection, correct sowing time, crop rotations and control of hosts assist in preventative management of rust.<sup>12</sup>

### 9.2.1 Common rust (caused by *Puccinia sorghi*)

This rust is found in most maize-growing areas but is more common in temperate and subtropical regions. Moderate temperatures (16–25°C), humid weather and leaf wetness durations of at least 6 h from rain or dew favour infection and disease development.

The disease is recognised by the abundant oval-elongate, red-brown pustules up to 2 mm long, which erupt through both leaf surfaces in scattered groups. This distinguishes common rust from polysora rust (see below), which has little development of rust pustules on the lower leaf surface. The pustules contain numerous powdery spores that can be spread long distances by wind.

Common rust survives between seasons only on living maize plants.

The only practical control measure is to plant resistant hybrids. Sweet maize hybrids tend to be most susceptible.<sup>13</sup>

### 9.2.2 Polysora rust or tropical rust or southern maize rust (caused by *Puccinia polysora*)

Polysora rust is favoured by warm, wet weather and is, therefore, a disease of tropical regions. Similar to common rust, it needs a long period of leaf wetness for infection. Severely affected leaves can die, which results in lighter than normal ears.

Small red-brown or orange pustules develop evenly over the upper leaf surfaces, and larger elongated pustules may also develop on the midribs, ear husks and tassels. Polysora rust survives between seasons only on living maize plants.<sup>14</sup>

## 9.3 Smuts

### 9.3.1 Boil smut or common smut (caused by *Ustilago zeae*, formerly known as *U. maydis*)

Boil smut occurs in most production areas but is often sporadic and minor.

All aboveground parts of the plant can be infected, but particularly the actively growing tissues on cobs, tassels and stems. Blisters or galls develop, initially with a thin white membrane and later containing black powdery spores. Mature galls can grow as large as 20 cm in diameter. (The fungus forms galls on all aboveground parts of maize species, and is known in Mexico as the food delicacy huitlacoche; it is eaten, usually as a filling, in quesadillas and other tortilla-based foods, and soups.)

Spores can be spread by wind, seed, clothes or farm machinery and can survive in the soil for many years. The spores germinate under the right conditions and produce another type of spore that is transported to the plant via the air.

Most hybrids have a reasonable level of resistance to boil smut. However, it is important to practice good crop hygiene and ensure that seed is treated with a registered fungicide.<sup>15</sup>

<sup>12</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

<sup>13</sup> QDAF (2012) Diseases affecting maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/diseases>

<sup>14</sup> QDAF (2012) Diseases affecting maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/diseases>

<sup>15</sup> QDAF (2012) Diseases affecting maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/diseases>

**i MORE INFORMATION**

C Beckingham, A Watson (2006) Boil smut of corn. DPI PrimeFact 247.

Corn smut. Wikipedia.



Young seedlings become swollen and distorted. Infections during the vegetative stage of growth are expressed as galls (boils) on the stems, leaf axils and leaves, which are initially pale green and become white and full of black powdery spores at maturity. In more mature plants, boils form in kernels, causing them to enlarge and deform, distorting the cob.

The fungus develops at temperatures >25°C and in dry conditions; however, it spreads in rain or high humidity. High levels of soil nitrogen also favour the fungus, and physical damage incurred from mechanical disturbance, for example, can increase infection. Spores are dispersed by wind and through contact sources. Inoculum may remain viable in soil for many years. Although losses are not usually significant, occasionally yield loss is severe.

Varietal selection may assist in reducing risk of infection; however, an integrated management program is necessary for greater effectiveness. This involves: cleaning machinery and boots to reduce contamination, regularly inspecting crops, removing infected plants, minimising plant injuries, careful rotations and applying seed treatments. Vitavax®200FF is the only registered chemical seed treatment available. Burning stubble may also be effective in reducing inoculum that may overwinter.<sup>16</sup>

Boil smut looks bad when found in a crop, but it affects only a very small percentage of maize crops. It is not poisonous; however, some states such as Tasmania ask for certification of freedom of boil smut in a crop. This is nearly impossible to certify because, once the crop is harvested, it is difficult to pick up in the grain, and it can be found in most crops. In most cases, the maize is part of a feed ration, and so it is not a threat to be spread through planting.

### 9.3.2 Head smut (caused by *Sporisorium reilianum*)

This fungus causes the replacement of part or all of the cob, and often the tassel, with black masses of powdery spores. At first, these masses are covered by a white membrane, which later bursts. Leafy structures may replace the reproductive tissues. Badly affected plants may be stunted and have profuse tillering.

Infection initially occurs when spores in the soil germinate and infect seedlings. The fungus then grows through the plant, ultimately invading the developing cobs and tassels. Infection is favoured by soil with low moisture levels and temperatures of 21–28°C.

Plant resistant hybrids and avoid early planting of susceptible varieties.<sup>17</sup>

### 9.4 Wallaby ear

Affected plants are often stunted, and their leaves are dark green or green-blue, have thickened veins, and are held at an acute (upright) angle. The disorder is more common in subtropical coastal areas, where it can severely affect yield. It occurs when a toxin is injected into the plant by the jassid (leafhopper) *Cicadulina bimaclata* while feeding.<sup>18</sup>

The condition is the result of the plant's reaction to the toxin injected by the jassid. This particular species mostly occurs in northern coastal areas of NSW, where significant damage may result. However, the condition is not of a large scale in most years.

Wallaby ear expresses as shortened leaves held upright, with veins on the lower leaf surface markedly thickened and often dark green or blue-green in colour.

Seasonal conditions that promote the proliferation of jassid populations will see a greater incidence of the condition.

<sup>16</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

<sup>17</sup> QDAF (2012) Diseases affecting maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/diseases>

<sup>18</sup> QDAF (2012) Diseases affecting maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/diseases>



There are no insecticides registered for the control of jassids in maize in NSW.<sup>19</sup>

## 9.5 Viruses

### 9.5.1 Johnson grass mosaic virus

Johnson grass mosaic virus (JGMV) is a disease of temperate and subtropical areas, and can be a serious problem in southern Queensland.

Many maize hybrids have good resistance, although sweet maize varieties, especially supersweet types, are highly susceptible if planted late in the season.

Symptoms are either a ring-spot pattern or a mosaic of light and dark green patches on the leaves. Plants of highly susceptible hybrids can have yellow leaves, may be small and suffer considerable yield loss.

The virus survives in Johnson grass and in old or ratoon forage and grain sorghum crops between seasons. It is spread by aphids and transmitted after a short feeding time.

Planting resistant hybrids is the main control measure for this disease, although sweet maize is highly susceptible. Control Johnson grass on your farm.<sup>20</sup>

### 9.5.2 Maize dwarf mosaic virus

MDMV appears as striping and mottling of leaves, which may be confused with zinc deficiency symptoms. Sometimes there are dark green 'islands' surrounded by lighter coloured rings. An overall yellowing of plants is common and some may become stunted. The virus may cause husks to gape, which can result in higher incidence of grain rot.

The virus is spread from diseased plants to healthy plants by several species of aphids. Sorghum and grasses such as Johnson grass are also hosts that contribute to the overwintering of disease and increase the risk of infection in late-planted crops. If infection occurs at an early stage, stunting and subsequent reductions in yield and grain quality can result.

There are moderately resistant varieties available to reduce risk of infection; however, it is also important to manage disease agronomically by controlling volunteer weeds and maize plants and monitoring crops regularly.<sup>21</sup>

## 9.6 Rots of stored grain

If grain is stored at 15–20% moisture and 21–32°C temperature, there is a higher probability of grain rots developing. On the other hand, grain moisture of <15% and temperatures <10°C pose little risk of damage from fungi.

Storage rots are caused by many fungi, but mainly species of *Aspergillus* and *Penicillium*.

Ruptured kernels will sometimes attract some species of *Fusarium*, another reason to set the header up correctly to avoid broken or damaged grain.

Invasion of whole kernels in storage results in discoloration, heating, caking and mustiness. One storage rot, known as 'blue-eye' is characterised by a bluish green germ.<sup>22</sup>

### MORE INFORMATION

[Diseases affecting maize. QDAF Queensland.](#)

[Photo gallery of diseases affecting maize. QDAF Queensland.](#)

[PR Harvey \*et al.\* \(2006\) Emerging soil-borne constraints to irrigated maize: a \*Pythium–Fusarium\* root disease complex.](#)

[A Watson \*et al.\* \(2006\) \*Fusarium\* spp. associated with ear rot of maize in the Murrumbidgee Irrigation Area of NSW.](#)

<sup>19</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

<sup>20</sup> QDAF (2012) Diseases affecting maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/diseases>

<sup>21</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

<sup>22</sup> QDAF (2012) Diseases affecting maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/diseases>



## MORE INFORMATION

[N Moore \*et al.\* \(2014\) Summer crop production guide. NSW DPI Management Guide.](#)

[A Watson \(2007\) Fusarium cob rot of corn. NSW DPI Primefact 243.](#)

## 9.7 Mycotoxins and mycotoxicoses

Mycotoxins are fungal metabolites that are toxic when consumed by animals or humans. Mycotoxins can accumulate in maturing maize standing in the paddock or in grain during transportation and storage under conditions of moisture, humidity and temperatures favorable for growth of the toxin-producing fungus or fungi.

Diseases in animals and humans resulting from the consumption of mycotoxins are termed mycotoxicoses.

The effects range from loss of appetite, feed refusal and decreased feed efficiency to mortality in domestic animals. There is also elevated body temperature and decreased feed intake.

Three genera of fungi—*Aspergillus*, *Penicillium* and *Fusarium*—are most frequently involved in cases of mycotoxin contamination in maize (Table 1). *Aspergillus flavus* produces aflatoxins in maize starting at a moisture content of ~18% and at temperatures of 12–42°C (optimum 25–32°C).

For more details on mycotoxins, visit [Maize Association of Australia](#) and look for the findings and recommendations by John Kopinski and Barry Blaney in [Managing Mycotoxins in Maize](#).<sup>23</sup>

<sup>23</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

SECTION 9 MAIZE

TABLE OF CONTENTS

FEEDBACK

**Table 1: Cob and stalk rots associated with mycotoxins of concern in NSW maize crops.**

Disease symptoms	Disease infection and spread	Mycotoxin characteristics	Conditions favouring mycotoxin development	Good agricultural practice to prevent grain contamination
<p><b>Aspergillus cob rot</b></p> <p>Greenish–grey mould growth affecting a small proportion of kernels in a small number of cobs. Infections tend to be limited to a small section of the field, for example an area of shallower soil where moisture stress occurs between irrigations.</p>	<p><i>Aspergillus</i> spp. (most commonly <i>A. flavus</i>) enter the crop as wind–blown spores that are highly resistant to desiccation. Fungi access to the developing kernels via the silks and sites of physical damage to the ear from insects or birds. Once fungal growth has begun it continues until grain moisture content (MC) falls below 14%. <i>Aspergillus</i> spp. are tolerant of hotter conditions than many other fungal diseases (<i>A. flavus</i> 12–43°C, optimum is 30°C).</p> <p><i>A. flavus</i> is also known as a ‘storage fungus’ as it grows at low moisture contents. Temperature fluctuations in grain stored slightly above 14% MC will cause small amounts of ‘available moisture’ to migrate into pockets. This creates opportunities for the fungi to grow. Initially it will grow in just the few infected kernels, but as moisture is released from the grain by the fungal growth the rate of new infection increases. The process is accelerated by storage insects.</p>	<p><b>Aflatoxins</b></p> <p><i>A. parasiticus</i> produces aflatoxins B1 and B2 while <i>A. flavus</i> produces B1, B2, G1 and G2. Aflatoxin B1 is one of the most potent liver carcinogens known. Aflatoxins can also cause acute effects when ingested by humans or animals in high doses.</p> <p>No natural cases of human disease caused by aflatoxin have been recorded in Australia, but livestock have occasionally been poisoned.</p> <p><b>Ochratoxin A</b></p> <p>Produced by <i>A. ochraceus</i> and <i>A. niger</i>. Causes kidney damage and immunosuppression in animals and is classified as a possible human carcinogen.</p>	<p>The critical period for aflatoxin production begins 20 days after anthesis. At this time aflatoxin development is favoured if; average day/night temperatures exceed 27°C and approach 32°C, there is persistent high humidity through grain maturation and the ear dries prematurely.</p> <p>In stored grain, very high concentrations can quickly develop if the moisture content is 16–20%.</p> <p>Little is known about factors promoting ochratoxin A. Its occurrence is much less common in Australia than aflatoxins. Until more is known it is reasonable to assume that managing aflatoxins will also minimise the risk of ochratoxin A.</p>	<p><b>Pre–plant</b></p> <p>Select hybrids that are adapted for the local conditions.</p> <p>Before planting, calculate water budgets to match the area of crop to the available water allocation.</p> <p>Do not stress crops by increasing the irrigation interval, particularly during grain fill.</p> <p><b>Planting</b></p> <p>Choose planting times that minimise exposure to hot temperatures during kernel formation.</p> <p><b>Growing</b></p> <p>Where hot conditions cannot be avoided during grain fill, monitor crop water use, reducing irrigation intervals as required.</p>
<p><b>Fusarium cob and stalk rots</b></p> <p>Powdery or cottony whitish– pink fungal growth on stalk nodes, in internal stalk tissue and on clusters of kernels scattered randomly over the ear. Kernels become tan or brown and often appear with a ‘starburst’ pattern of fine cracks – produced by sudden contraction and expansion of the grain pericarp (skin).</p>	<p><i>Fusarium</i> spp. (commonly <i>F. verticillioides</i>) overwinters in crop residues and spreads by wind–blown spores. Infections are systemic, also possible via seed transmission. Infection becomes pathogenic when drought stress before and during silking is followed by warm, wet conditions during grain fill (causing sudden change in the grain pericarp). Infection tends to be more severe in dense plant stands and crops damaged by insect attack. Higher risk of stalk infection is associated with maize following a pasture phase in the rotation. <i>Fusarium</i> spp. require moisture contents above 18.4% for growth in kernels.</p>	<p><b>Fumonisin</b></p> <p><i>F. verticillioides</i> is presumed to be the main source of fumonisins in Australia, however several other <i>Fusarium</i> spp. capable of fumonisin production in maize. Fumonisin are particularly toxic to horses causing liquefaction of the brain. In pigs they cause pulmonary oedema. Cattle, sheep and poultry are fairly resistant. Their role in human diseases is still being investigated but they have been associated with oesophageal cancer.</p>	<p>Fumonisin production occurs when the plant’s defences and the activity of a beneficial fungus, <i>Acremonium zeae</i>, are impaired by moisture stress or physical damage. Fumonisin is more likely to be produced where grain endosperm has been exposed.</p> <p>Due to the high moisture and humidity requirements of <i>Fusarium</i> spp., development of fumonisins in stored grain is highly unlikely.</p>	<p>Adjust irrigation across the field to counter areas of soil with lower water holding capacity.</p> <p>Closely monitor heliothis and armyworm.</p> <p><b>Harvest</b></p> <p>Avoid harvest delays. Consider harvesting at a higher moisture content and artificially drying grain below 14% for storage.</p> <p>At harvest minimise light weight material in the sample. Damaged kernels or poorly filled kernels are more likely to carry <i>Aspergillus</i> spp. and <i>Fusarium</i> spp.</p>
<p><b>Gibberella cob and stalk rots</b></p> <p>Rotting stalks exhibit reddish– pink discolouration of internal tissues. Hard, black, globular fruiting bodies (perithecia) may be found on the exterior surfaces of the stalks and exterior husks of infected cobs. Infected cobs fill with reddish– pink to dark purple fungal rot extending from the tip of the ear towards the base. Husks tend to bind to the kernels.</p>	<p><i>Fusarium graminearum</i> (formerly <i>Gibberella zeae</i>) survives in the residues of many field crops – wheat, maize, rice, sorghum and pasture grasses. Release of ascospores that initiate infection is triggered by cool, wet, humid conditions, from silking through grain maturation. Favourable conditions are more common in the north and central coast and tableland regions. The disease is not easily distinguished from <i>Fusarium</i> stalk rot.</p>	<p><b>Zearalenone</b></p> <p>Produced by <i>F. graminearum</i>, this mycotoxin is implicated in some forms of infertility in pigs, cattle and sheep. It has not been proven to affect human health.</p> <p><b>Trichothecenes</b></p> <p>Primarily produced by <i>F. graminearum</i>, but other <i>Fusarium</i> spp. maybe involved. Of the 150 related toxins, DON (deoxynivalenol) is the most important to NSW maize production. It is known to survive processing and be present in human food products. Acute exposure can suppress appetite, induce vomiting and affect the immune system.</p>	<p>Incidence of zearalenone is infl ed by rainfall at silking and the relative cob rot resistance and husk covering of the maize hybrid.</p> <p>In NSW, the occurrence of DON has to date been limited to the Liverpool Plains region when abnormally cool and persistently moist conditions occurred through grain maturation.</p>	<p>Harvest areas of the field affected by moisture stress separately.</p> <p><b>Storage</b></p> <p>Store grain at 12% MC, maintain constant storage temperature and control insect pests.</p>

 **MORE INFORMATION**

[Disease control in summer crops and management strategies to minimise financial losses](#)

## 9.8 Summer crops as host species

Summer crops play an important part in the varied farming systems from central NSW to Central Queensland where they provide a break for wheat diseases, while enabling weed-management options and crop-income diversity.

Integrated disease management (IDM) of the major diseases of summer crops, through various combinations of plant resistance, fungicides, planting seed selection, planting time, paddock selection and other agronomic practices, has been the focus of the joint University of Southern Queensland (USQ) and Queensland Department of Agriculture and Fisheries summer field crops pathology team.

Examples of IDM include: the strategic use of fungicides and resistance to manage rust and leaf spot of peanuts and powdery mildew of mungbeans; and resistance/tolerance studies and planting strategies to manage tobacco streak virus in sunflowers and other crops in Central Queensland.

The current focus of research is on the roles that all crops (and weeds) in the varied farming systems play in biology of pathogens of summer field crops to provide improved management options.

The researchers are finding that some pathogens have a much wider host range than previously thought.

Some newly found *Diaporthe* (*Phomopsis*) species are capable of causing stem cankers on sunflowers, soybeans and mungbeans and a range of other crops, but can also infect a range of live weeds and weed stubble; others can infect 'host' plants without causing symptoms, such as the damaging *D. gulyae* on maize.

Similarly, *Fusarium thapsinum*, which is a major cause of sorghum stalk rot, has been shown to be capable of invading living plants of 'non-hosts' including chickpeas, mungbeans and maize, with no symptoms being displayed.

Plant residues are an important mode of survival of many plant pathogens, including species of *Diaporthe* and *Fusarium*.

Traditionally, infected residues of the recognised major hosts, for example sorghum infected with *F. thapsinum*, charcoal rot on sunflowers, sorghum and soybeans and *Diaporthe* species on sunflowers and soybeans, have been considered to be the main means of survival from season to season. However, preliminary findings suggest that residues of asymptomatic non-hosts including crops and weeds may play a similarly important role and can be a reservoir for disease.

These findings have farm-scale implications, particularly with respect to stubble and weed management and crop sequences.<sup>24</sup>

<sup>24</sup> R Kimber (2015) Close monitoring shows changing pathogen strains. Ground Cover Issue 116, 4 May 2015, <https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-116-Foliar-fungal-diseases-of-pulses-and-oilseeds/Close-monitoring-shows-changing-pathogen-strains>

# Plant growth regulators and canopy management

Not applicable for this crop.

# Crop desiccation/spray out

Not applicable for this crop.



# Harvest

## 12.1 Timing

Crop maturity from planting to grain harvest stage takes 4.5–6 months, depending on variety, seasonal conditions and time of planting. Slower varieties tend to yield more than quick varieties.<sup>1</sup>

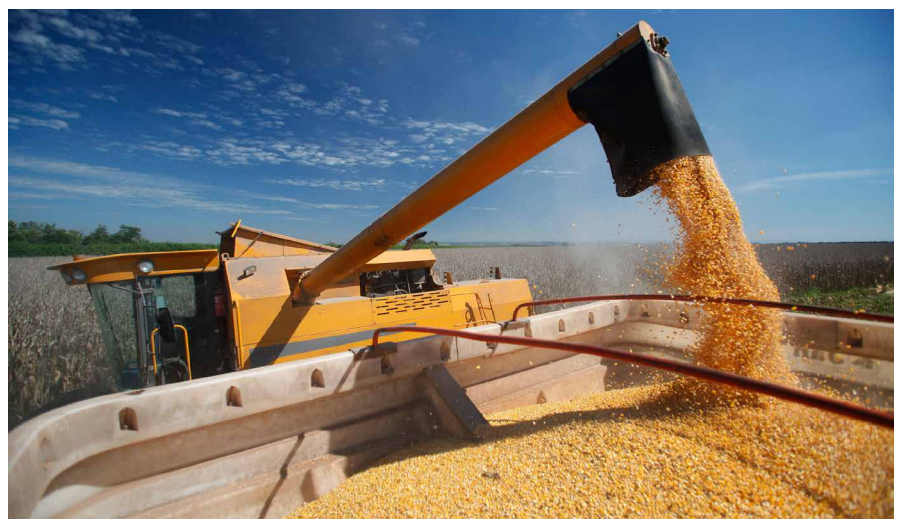
Most end users require grain moisture content at 12–14%, with 12% being optimal for storage on-farm. As grain reaches physiological maturity, moisture content is usually 28–34%, which requires significant drying down. Natural dry down is possible until early May, depending on location.

Maize can dry at a rate of 0.5–1.0% each day in suitable weather conditions. Once conditions become cool and the likelihood of rain increases, crops can be harvested at 16–18% moisture content and artificially dried to <14%, if returns for grain support this or if poor weather conditions are imminent. Crops can be left to stand over winter for natural drying to resume in the spring, but this increases the risk of mycotoxin contamination.

With access to drying facilities, harvest usually commences at 18% grain moisture content (Figure 1). Most harvesters perform best, losing and damaging less grain, when moisture content is 18–24%. Aeration equipment is not sufficient to dry maize grain down to 14% moisture.<sup>2</sup>

Hybrids with loose husk cover dry down faster than those with tight covers.

Although grain can physically be harvested at up to 25% moisture, this is not recommended because drying costs will be high. Where possible, growers should aim to harvest as close as possible to the required delivery moisture percentage.<sup>3</sup>



**Figure 1:** Most harvesters perform best, losing and damaging less grain, when moisture content is >18%.

1 QDAF (2012) Harvesting and marketing for maize. Maize production. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/harvesting-marketing>

2 N Moore, L Serafin, L Jenkins (2014) Summer crop production guide. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

3 QDAF (2012) Harvesting and marketing for maize. Maize production. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/harvesting-marketing>

 **MORE INFORMATION**

DW Robinson, CA Kirby (2002) Maize stubble management survey. CSIRO Technical Report 13/02.

## 12.2 Grain for milling markets

Grain destined for milling markets requires special care during harvest and preparation for storage. Grain with a high proportion of hard endosperm, as required for dry milling, is highly susceptible to hairline fractures known as 'stress cracks', in which moisture evaporates from the endosperm, shrinking it. When drying occurs too quickly, shrinkage is uneven, leading to the formation of cracks. During milling, grits break up along the cracks, making them unsuitable for products such as cornflakes.

To reduce the occurrence of stress cracks:

- Use lower drum speeds during harvest.
- Use large-diameter augers (>200 mm) operating at low speeds and maximum holding capacity.
- Use conveyor belts in preference to augers.
- Reduce moisture content of grain harvested >14% by using slow, steady drying rates with heated air temperatures not exceeding 49°C and grain temperature not exceeding 38°C.
- Slowly cool grain that has been dried; ideally, dry grain early in the day to enable slow cooling as the temperature decreases into the evening.
- Prevent re-wetting of grain from dew, condensation or rain.
- Minimise the number of times the grain is handled.<sup>4 5</sup>

## 12.3 Black layer or physiological maturity

When the crop reaches physiological maturity, or 'black layer', the grain moisture is ~28–34%. This occurs ~60–66 days after silking. Dry down after reaching black layer can vary from 0.5% to 2% moisture per day for early-planted crops maturing during January–February in heatwave conditions. However, during the cooler and often wetter winter months, maize does not come down in moisture much below 16%, until the weather starts to warm again (this more of an issue with later plants).

The softer endosperm types and particularly the loose-husk-covered hybrids dry down quicker than the tighter husk-covered, harder endosperm types.

Sometimes a decision has to be made, if stalk rot is causing some lodging, about whether to harvest early and dry the grain (even though at an additional expense) or to leave it to the optimum moisture but risk much higher field losses.

Grain harvesting is normally done with a corn front with either a snapper front, which only removes the ear and takes very little plant material through the header, or a cutter bar, where chains feed the crop onto the cutter bar (Figure 2). Dryland growers with lower yielding crops will also use sunflower trays, which divide and guide the crop onto the cutter bar, but they are not as efficient in high-yielding crops. Local experience suggests that dryland crops of <6 t/ha can be harvested using conventional fronts with sunflower trays.

As with planting the crop, groundspeed is important because it affects the intake grain quantity—too much means grain losses over the top sieve. Header manuals should be followed for setting up the header with regard to drums, rotors and cylinders. The optimum cylinder speed for maize is usually ~350–450 rpm.

<sup>4</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

<sup>5</sup> QDAF (2012) Harvesting and marketing for maize. Maize production. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/harvesting-marketing>

## SECTION 12 MAIZE

TABLE OF CONTENTS

FEEDBACK



**Figure 2:** Grain harvesting is normally done with a corn front with either a snapper front or cutter bar (pictured).

Photo: Pacific Seeds

Rotor speeds should be as fast as practical without cracking the grain. Concave settings are also important; as a guide, the clearance at the back of the concave equals the diameter of the cobs.

Not only will a poorly set up header crack grain but with some of the specialty maize such as gritting maize for grit manufacture and popcorn, it can cause hairline stress fractures. Most contracts accept only minimum damage. With the new opportunities in export markets, cracking of the grain can also be an issue with tight specifications to be met. Post-harvest handling of this type of material is also crucial because augers can be very abrasive and will have the same effect as grain falling from a great height into silos.

Stress fracturing can also happen with standing crops in the paddock, particularly the harder endosperm types with little tip coverage, looser husk cover and quicker dry down, and in autumn if the difference between night and daytime air temperature is >30°C.

Incorrect artificial drying can also cause stress fractures, either from excessive heat (>50°C) when trying to dry too quickly, or if the grain is allowed to cool down too quickly with very cold outside air.

Maize at 15–16% moisture can be stored over the cooler months using aerators, but once the weather starts to warm up moisture will need to come down to 14%.

As with all stored grain (or even standing crops, particularly late ones), insects will attack, particularly in humid conditions; therefore, attention needs to be given to applying insecticides or Insectigas® if storing for a period.<sup>6</sup>

### MORE INFORMATION

[Maize Trading Standards, 2014/15.](#)  
[Grain Trade Australia.](#)

[Australian Pesticides and Veterinary Medicines Authority.](#)

[Maize Association of Australia.](#)

<sup>6</sup> Pacific Seeds (2008/2009) Hybrid corn agronomy guide 2008/09, Pacific Seeds Pty Ltd, <https://www.yumpu.com/en/document/view/34525585/pacific-seeds-hybrid-corn-agronomy-guide-2008-directroutercom>

**i MORE INFORMATION**

[Stored Grain Information Hub](#)

# Storage

There are four key best practice strategies that provide good results for on farm storage. When combined, they form the foundation for successful storage and importantly, a grower can build a reputation as a reliable supplier of quality grain.

**Aeration:** correctly designed and managed, will provide cool grain temperatures and uniform grain moisture conditions. The result is reduced problems with grain moulds and insect pests in storage, plus the ability to maintain grain quality attributes such as germination, pulse seed colour, oil quality and flour quality.

**Hygiene:** a good standard of storage facility hygiene is crucial in keeping storage pest numbers to a minimum and reducing the risk of grain contamination.

**Monitoring:** monthly checking of grain in storage for insect pests (sieving / trapping) and at the same time inspect grain quality and temperature. Keep a monthly storage record to record these details, including any grain treatments you applied.

**Fumigation:** in Australia we now only have gases (fumigation) to deal with insect pest infestations in stored grain. To achieve effective fumigations the storage/silo must be sealable — gas-tight (AS2628) to hold the gas concentration for the required time.<sup>1</sup>

### Key points

- Aeration is an important feature of maize storage in the northern region. It has several roles including cooling maize post-harvest, short-term storage of maize with higher grain moisture contents, aeration drying and aeration cooling following hot air drying.
- Good storage and equipment hygiene should be practiced with maize to avoid contamination of other stored crops such as wheat, which can be downgraded by even small amounts of residual maize seed.
- Maize gritting and feed varieties must be carefully segregated in storages and accurate records maintained to ensure market specifications for various end uses can be met.
- Maize is one of the few grain crops that can harbour a field infestation of weevils (*Sitophilus zeamais*) at harvest time. Sieve grain samples from trucks during harvest time to assess whether there is a field infestation.

An on-farm storage system that has aeration capabilities and is fully sealable is essential for growers who wish to maximise their returns from maize. Without pressure-tested, sealable silos, growers could be contributing to Australia’s problem of insect resistance to phosphine, the most common fumigant used in the Australian grain industry. Without aeration cooling, growers are increasing the likelihood of regular pest infestation and problems with mouldy grain.

In conjunction with sound management practices, which include regular monthly monitoring and recording for storage pests and grain quality, ensuring aeration systems are operating efficiently, and good hygiene levels, an on-farm storage system that is well designed and maintained provides the best insurance for the grower on the quality of grain to be out-turned.

Grain Trade Australia stipulates standards for heat-damaged, bin-burnt, storage-mould-affected or rotten wheat, all of which can result in the discounting or rejection

<sup>1</sup> P Burrill (2016) Part I Achieving great aeration results and Part II Silo recirculation as an aid to fumigation. GRDC Update Papers 20 July 2016. <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Part-I-Achieving-great-aeration-results-and-Part-II-Silo-recirculation-as-an-aid-to-fumigation>



**i MORE INFORMATION**

[Northern southern regions stored grain pests—identification. GRDC Stored Grain Information Hub.](#)

[Stored grain pests identification—the back pocket guide 2011. GRDC Stored Grain Information Hub.](#)

[SC Kimenju, H De Groot \(2010\) Economic analysis of alternative maize storage technologies in Kenya. AAAE/AEASA Conference.](#)

[EY Hosang \(2012\) An alternative storage technique for maintaining maize seed quality in West Timor. Australian Agronomy Conference.](#)

**i MORE INFORMATION**

[GCTV2: National Standard for Sealed Silos](#)

of grain.<sup>2</sup> Effective management of stored grain can eliminate all of these risks to quality.

### 13.1 How to store maize on-farm

According to the Kondinin Group National Agricultural Survey 2011, silos account for 79% of Australia’s on-farm grain storage, compared with 12% for bunkers and pits and 9% for grain bags.

Aerated, sealable silos are widely acknowledged as the most effective ways to store grain on-farm (Table 1). There is no compulsory manufacturing standard for sealed silos in Australia; however, a voluntary industry standard was adopted in 2010.

**Table 1: Advantages and disadvantages of grain storage options.**

Storage type	Advantages	Disadvantages
Gas-tight sealable silo	<ul style="list-style-type: none"> <li>Gas-tight sealable status allows phosphine and controlled atmosphere options to control insects</li> <li>Easily aerated with fans</li> <li>Fabricated on-site or off-site and transported</li> <li>Capacity from 15 tonnes up to 3000 tonnes</li> <li>Up to 25 year plus service life</li> <li>Simple in-loading and out-loading</li> <li>Easily administered hygiene (cone base particularly)</li> <li>Can be used multiple times in-season</li> </ul>	<ul style="list-style-type: none"> <li>Requires foundation to be constructed</li> <li>Relatively high initial investment required</li> <li>Seals must be regularly maintained</li> <li>Access requires safety equipment and infrastructure</li> <li>Requires an annual test to check gas-tight sealing</li> </ul>
Non-sealed silo	<ul style="list-style-type: none"> <li>Easily aerated with fans</li> <li>7–10% cheaper than sealed silos</li> <li>Capacity from 15 tonnes up to 3000 tonnes</li> <li>Up to 25 year plus service life</li> <li>Can be used multiple times in-season</li> </ul>	<ul style="list-style-type: none"> <li>Requires foundation to be constructed</li> <li>Silo cannot be used for fumigation —see phosphine label</li> <li>Insect control options limited to protectants in eastern states and dryacide in WA.</li> <li>Access requires safety equipment and infrastructure</li> </ul>

<sup>2</sup> GTA (2013) Wheat Standards, 2013/2014 season. Grain Trade Australia, August 2013, <http://www.graintrade.org.au/sites/default/files/file/Commodity%20Standards/Section%202%20-%20Wheat%20Standards%20201314.pdf>



Storage type	Advantages	Disadvantages
Grain storage bags	<ul style="list-style-type: none"> <li>• Low initial cost</li> <li>• Can be laid on a prepared pad in the paddock</li> <li>• Provide harvest logistics support</li> <li>• Can provide segregation options</li> <li>• Are all ground operated</li> <li>• Can accommodate high-yielding seasons</li> </ul>	<ul style="list-style-type: none"> <li>• Requires purchase or lease of loader and unloader</li> <li>• Increased risk of damage beyond short-term storage (typically three months)</li> <li>• Limited insect control options, fumigation only possible under specific protocols</li> <li>• Requires regular inspection and maintenance which needs to be budgeted for</li> <li>• Aeration of grain in bags currently limited to research trials only</li> <li>• Must be fenced off</li> <li>• Prone to attack by mice, birds, foxes etc.</li> <li>• Limited wet weather access if stored in paddock</li> <li>• Need to dispose of bag after use</li> <li>• Single-use only</li> </ul>
Grain storage sheds	<ul style="list-style-type: none"> <li>• Can be used for dual purposes</li> <li>• 30 year plus service life</li> <li>• Low cost per stored tonne</li> </ul>	<ul style="list-style-type: none"> <li>• Aeration systems require specific design</li> <li>• Risk of contamination from dual purpose use</li> <li>• Difficult to seal for fumigation</li> <li>• Vermin control is difficult</li> <li>• Limited insect control options without sealing</li> <li>• Difficult to unload</li> </ul>

Growers should pressure-test sealable silos once per year to check for damaged seals on openings. Storages must be able to be sealed properly to ensure effective fumigation.

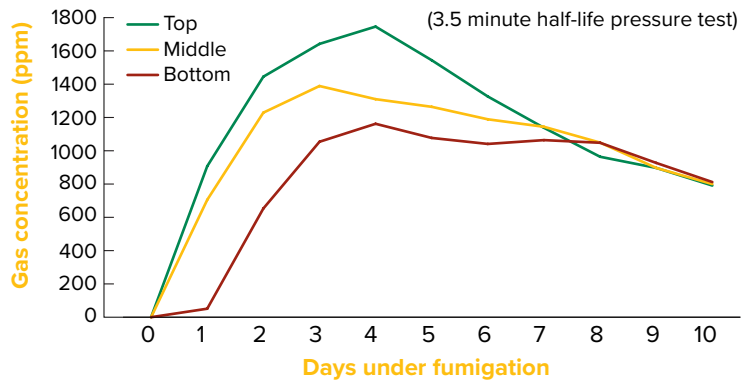
At an industry level, it is in growers' best interests to fumigate grain in sealable storages to help stem the rise of insect resistance to phosphine. This resistance has come about because of the prevalence of silos that are poorly sealed or unsealed during fumigation.<sup>3</sup>

The Kondinin Group National Agricultural Survey 2009 revealed that 85% of respondents had used phosphine at least once during the previous 5 years, and of those users, 37% used phosphine every year for the past 5 years. A GRDC survey during 2010 revealed that only 36% of growers using phosphine applied it correctly—in a gas-tight, sealed silo.

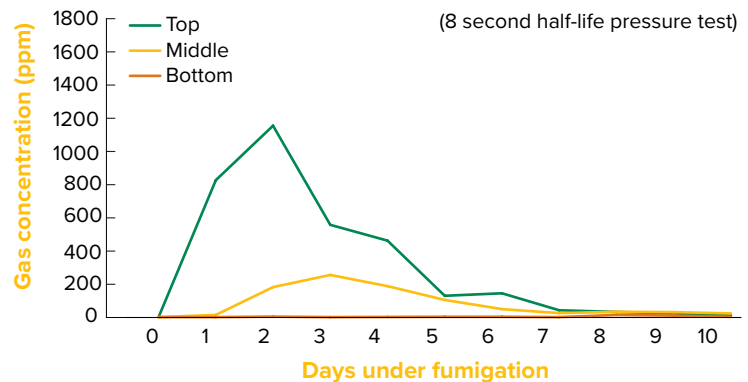
Research shows that fumigating in a storage that is not pressure-sealed does not achieve a sufficient concentration of fumigant for long enough to kill pests at all life-cycle stages. For effective phosphine fumigation, a minimum gas concentration of 300 parts per million (ppm) for 7 days or 200 ppm for 10 days is required (Figure 1). Fumigation trials in silos with small leaks demonstrated that phosphine levels are

<sup>3</sup> C Warrick (2011) Fumigating with phosphine, other fumigants and controlled atmospheres: Do it right—do it once: A Grains Industry Guide. GRDC Stored Grain Project, January 2011 (reprinted June 2013), <http://www.grdc.com.au//media/FC440FBD7AE14140A08DAA3F2962E501.pdf>

as low as 3 ppm close to the leaks (Figure 2). The rest of the silo also suffers from reduced gas levels.<sup>4</sup>



**Figure 1:** Gas concentration in gas-tight silo.



**Figure 2:** Gas concentration in a non-gas-tight silo.

To find out more about how to pressure-test silos, visit the GRDC Grains Industry Guide: [Fumigating with phosphine, other fumigants and controlled atmospheres. Do it right—do it once.](#)

Aeration of stored wheat is a key non-chemical tool used to minimise the risk of insect infestations and spoiling through heat and/or moisture damage.

Aeration controllers reduce the amount of time needed to physically turn fans on and off and they increase the reliability of grain cooling, but units and storage facilities must still be checked regularly. Most aeration controllers have hour meters fitted, so run-times can be checked to ensure that they are within range of the expected approximate average of 100 h/month.

Serious grain damage has occurred when fan performance has not met the required airflow rate as measured in litres per second per tonne (L/s.t). When grain with elevated moisture levels is cooled or dried, an inadequate airflow rate and/or a poor system design can cause sections of the storage to develop very high grain temperatures. When aeration drying, moisture drying fronts can be moving too slowly to prevent grain spoilage. Grain-quality losses from moulds and insect damage can

<sup>4</sup> P Botta, P Burrill, C Newman (2010) Pressure testing sealable silos. GRDC Grain Storage Fact Sheet, September 2010. <http://www.grdc.com.au/~media/0218DA4A22264A31B6202718043758DE.pdf>

**i MORE INFORMATION**

[Grain storage facilities: Planning for efficiency and quality.](#)

**i MORE INFORMATION**

[Double croppers warm to maize expansion](#)

occur rapidly. This type of damage often makes the grain difficult to sell and may cause physical damage to the silo itself.<sup>5</sup>

Researchers in Australia have developed a device that measures working airflow rates of fans fitted to grain storage. Called the 'A-Flow', it has been validated under controlled conditions, using an Australian Standard fan-performance test rig, to be within 2.6% of the true fan output. The device was used on a typical grain storage that was in the process of aerating recently harvested grain. A fan advertised to provide 1000 L/s (equivalent to 6.7 L/s.t on a full 150-t silo) was demonstrated to be producing only 1.8 L/s.t. Because of this test, the farmer recognised a need to make changes to his aeration system design.

Several changes may be required if airflow rates are not suitable for efficient aeration cooling or drying. A new fan that is better suited to the task could be installed, a second fan added, or the amount of grain in the silo reduced to increase flow rate per tonne of grain.

A GRDC Grain Storage Fact Sheet explaining how to build and use an A-Flow is available: [Performance testing aeration systems.](#)

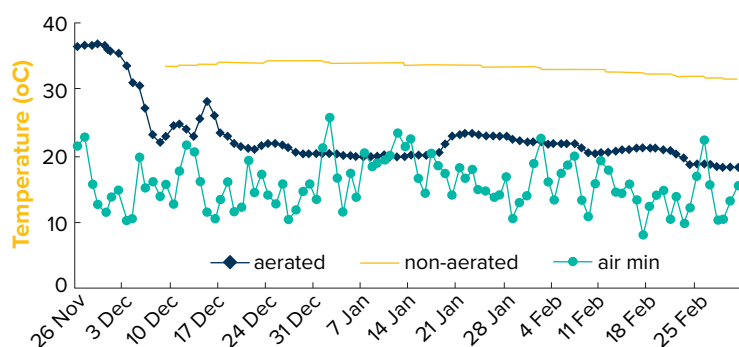
Detailed information about selecting, siting and fitting-out silos, grain storage bags, sheds and bunkers is contained in the GRDC Grains Industry Guide: [Grain storage facilities. Planning for efficiency and quality.](#)

### 13.2 Aeration during storage

Aeration is a vital part of the pest-control strategy, and reducing stored grain temperatures by at least 10°C during summer significantly reduces the threat of a serious insect infestation, helping to maintain grain quality.

For the summer storage period November to April, aim to achieve grain temperatures of 18° to 23°C with well managed aeration cooling (Figure 3). For the winter period May to September the target is grain temperatures of less than 15°C.

Push a robust thermometer attached securely to a broom handle, or better, a purpose built grain temperature probe one meter into grain. Leave for a few minutes in grain before reading to see what grain temperature your aeration system has achieved.<sup>6</sup>



**Figure 3:** Comparison of wheat grain temperatures in aerated and non-aerated silos in NSW. Non-aerated silo had grain temperature sit above 30°C for 3 months, ideal for insect breeding. Well managed aeration in summer brings temperatures down towards 20°C.

Source: Barry Wallbank, NSW DPI

5 P Burrill, A Ridley (2012) Performance testing aeration systems. GRDC Research Update Northern Region, Spring 2012, Issue 66, <http://www.grdc.com.au/media/DAF5F438D9644D90B9A4FA9716B2014E.pdf>  
 6 P Burrill (2016) Part I Achieving great aeration results and Part II Silo recirculation as an aid to fumigation. GRDC Update Papers 20 July 2016, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Part-I-Achieving-great-aeration-results-and-Part-II-Silo-recirculation-as-an-aid-to-fumigation>



Without aeration, grain is an effective insulator and will maintain its warm harvest temperature for a long time. Grain at typical harvest temperatures of 25–35°C and moisture content >14–15% provides ideal conditions for mould and insect growth (Table 2).<sup>7</sup>

Go ‘on-farm’ with Ground Cover TV to see an explanation of the national standard for sealed silos.



**Table 2:** Effect of grain temperature on insects and mould.

Grain temperature (°C)	Insect and mould development	Grain moisture content (%)
40–55	Seed damage occurs, reducing viability	
30–40	Mould and insects are prolific	>18
25–30	Mould and insects active	13–18
20–25	Mould development is limited	10–13
18–20	Young insects stop developing	9
<15	Most insects stop reproducing, mould stops developing	<8

Source: Kondinin Group

Although adult insects can still survive at low temperatures, most young storage pests stop developing at temperatures <18–20°C. At temperatures <15°C, the common rice weevil stops developing. Life cycles of insect pests (egg, larva, pupa and adult) are lengthened from the typical 4 weeks at warm temperatures (30–35°C) to 7–15 weeks at cooler temperatures (20–23°C).

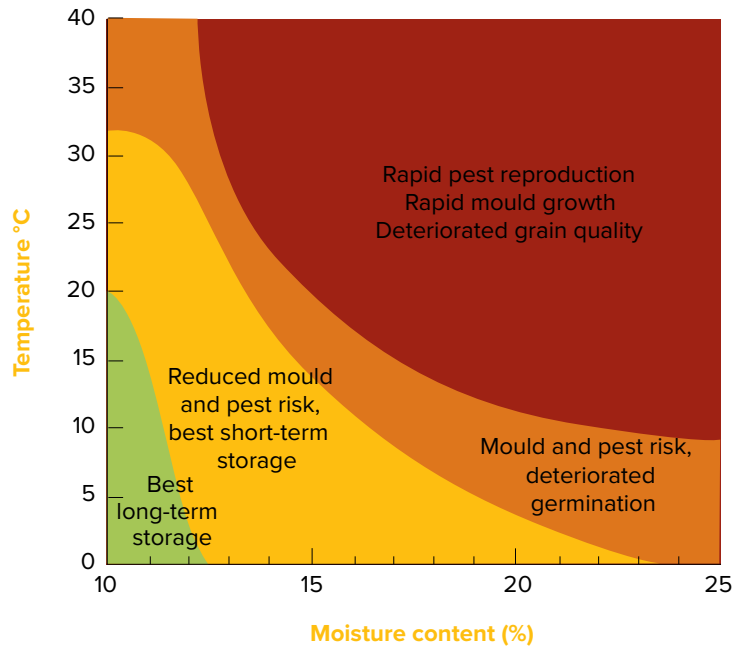
Research by the NSW Department of Primary Industries has shown that grain temperature should be kept <15°C to protect seed quality and stop all major insect infestations, and aeration slows the rate of deterioration of seed if the moisture content is kept at 12.5–14%.<sup>8</sup>

A pilot trial by the Queensland Department of Employment, Economic Development and Innovation showed how rapidly high-moisture grain generates heat when put into a confined storage, such as a silo. Wheat with 16.5% moisture content at a temperature of 28°C was put into a silo with no aeration. Within hours, the

<sup>7</sup> P Burrill, P Botta, C Newman, B White, C Warrick (2013) Dealing with high-moisture grain. GRDC Grain Storage Fact Sheet, June 2013, <http://www.grdc.com.au/~media/36D51B725EF44EC892BCD3C0A9F4602C.pdf>

<sup>8</sup> NSW Department of Primary Industries District Agronomists (2007) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

grain temperature reached 39°C and within 2 days reached 46°C, providing ideal conditions for mould growth and grain damage (Figure 4).<sup>9</sup>



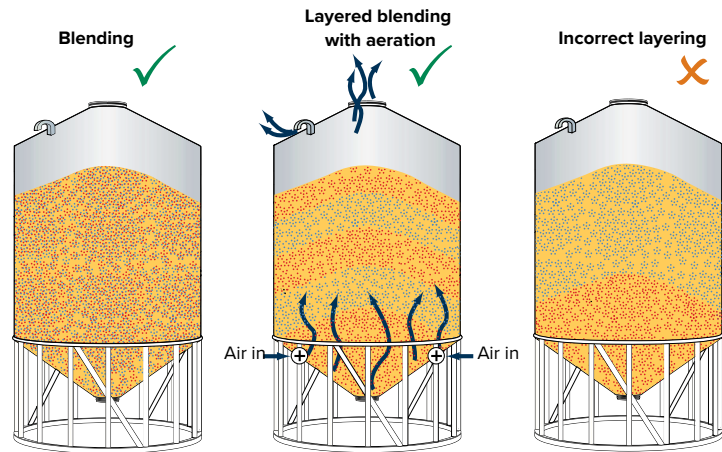
**Figure 4:** Effects of temperature and moisture on stored grain.

(Source: CSIRO Ecosystems Sciences as published in <http://www.grdc.com.au/~media/36D51B725EF44EC892BCD3C0A9F4602C.pdf>)

If use of a grain dryer is not an option, grain that is over the standard safe storage moisture content of 12% and up to the moderate moisture level of 15% can be managed in storage for short periods of time by continually running aeration cooling fans. However, grain needs to be promptly brought down to safe storage moisture contents by either blending with low-moisture grain, then aerating, or drying using heated air drying equipment followed again by aeration cooling (Figure 5).

<sup>9</sup> P Burrill, P Botta, C Newman, B White, C Warrick (2013) Dealing with high-moisture grain. GRDC Grain Storage Fact Sheet, June 2013, <http://www.grdc.com.au/~media/36D51B725EF44EC892BCD3C0A9F4602C.pdf>





**Figure 5:** Correct blending.

Source: Kondinin Group

Aeration drying forces large volumes of air through the grain in storage and slowly removes moisture. Supplementary heating can be added if high ambient humidity is a problem. It can be done in a purpose-built aeration-drying silo (e.g. Kotzur drying silo) or a partly filled silo with high-capacity aeration fans producing 15–25 L air/s.t.

Dedicated driers can be used to dry wheat in batches or with continuous-flow, before it is put into silos, but excessive heat applied post-harvest can reduce the quality of milling wheat or the germination of planting seed. Aeration drying can reduce these risks.

A wet harvest or damp conditions can make drying prior to storage a necessity. These rules will help you to decide whether it is safe to store your wheat without drying:

- Wheat that does not exceed the maximum moisture level of 12.5% can be cooled without drying to slow insect development and maintain quality during storage.
- For grain of up to 15% moisture, if drying equipment is not available immediately, moderately moist grain can be cooled for a short period to slow mould and insect development, then dried when the right equipment is available.
- After drying to the required moisture content, grain should be cooled to maintain quality.
- Grain of >15% moisture requires immediate moisture reduction before cooling for maintenance. If overheating occurs during artificial drying or because of over-moisture storage, some grains are likely to be deemed 'heat damaged' or 'bin burnt'.

To find out more, download the GRDC Fact Sheet [Dealing with high-moisture grain](#).

### 13.3 Hygiene

Effective grain hygiene and aeration cooling can overcome 70% of pest problems in stored grain. All grain residues should be cleaned out when silos and grain-handling equipment are not in use to help minimise the establishment and build-up of pest populations. In one year, a bag of infested grain can produce >1 million insects, which can walk and fly to other grain storages where they will start new infestations. Meticulous grain hygiene involves removing any grain that can harbour pests and allow them to breed. Grain pests live in dark, sheltered areas and breed best in warm conditions.



A trial in Queensland revealed >1000 lesser grain borers (*Rhyzopertha dominica*) in the first 40 L of grain through a harvester at the start of harvest; this harvester was considered reasonably clean at the end of the previous season.<sup>10</sup> Further studies in Queensland revealed that insects are least mobile during the colder months of the year. Cleaning around silos in midwinter (June, July) can reduce insect numbers before they become mobile.

Successful grain hygiene involves cleaning all areas where grain becomes trapped in storages and equipment. Grain pests can survive in a tiny amount of grain, which can go on to infest any parcel of fresh grain through the machine or storage. Harvesters and grain-handling equipment should be cleaned out thoroughly with compressed air after use.

After grain storages and handling equipment are cleaned, they should be treated with a structural treatment. Diatomaceous earth (DE) is an amorphous silica known commercially as Dryacide® and is widely used for this purpose. It acts by absorbing the insect's cuticle or protective exterior, causing death by desiccation. If applied correctly with complete coverage in a dry environment, DE can provide up to 12 months' protection by killing most species of grain insects and with no risk of resistance developing. It can be applied as a dust or slurry.

Although some grain buyers accept small amounts of residue on cereal grains from chemical structural treatments, growers should avoid using them, or should wash the storage out before storing oilseeds and pulses. Growers are advised to check the grain buyer's delivery standards for MRL allowances before using grain protectants or structural treatments.

To find out more about what to use and when and how to clean equipment and storages to minimise the chance of insect infestation, download the GRDC Grain Storage Fact Sheets [Hygiene and structural treatment for grain storages](#) (June 2013) and [Managing maximum residue Limits in export grains](#) (July 2014).

### 13.4 Monitoring grain

Growers are advised to monitor all grain storages at least monthly. For grain in higher risk situations, monitor every 2 weeks during warmer periods of the year. Insect pests present in on-farm storages must be identified so that growers can use the best of both chemical and non-chemical control measures to control them.

Thorough sampling and sieving for insects and quality inspections are required. Number all silos and storages and keep monthly records of insect pests found. Any grain treatments applied should also be recorded. If possible, the moisture and temperature of the grain at the bottom and top of the stack should be safely checked regularly.<sup>11</sup>

Rice weevil (*Sitophilus oryzae*), lesser grain borer (*Rhyzopertha dominica*) and rust-red flour beetle (*Tribolium castaneum*) are some of the most common insect pest found in stored cereals. Other species to watch for include psocids (booklice), saw-toothed grain beetle (*Oryzaephilus* spp.), flat grain beetle (*Cryptolestes* spp.), Indian meal moth (*Plodia interpunctella*) and angoumois grain moth (*Sitotroga cerealella*). Several other beetles, and mites, are sometimes present as pests in stored cereal grain and processed products.

Photographs and descriptions of these pests can be found in the GRDC Grain Storage Fact Sheet [Northern and southern regions stored grain pests—Identification](#)

This Fact Sheet also outlines how to monitor stored grain for infestations. Here are some basic points to follow when monitoring for insect pests in your grain:

#### MORE INFORMATION

[Grain Storage Fact Sheet: Stored Grain Pests Identification](#)

<sup>10</sup> P Burrill, P Botta, C Newman, B White, C Warrick (2013) Northern and southern regions—Grain storage pest control guide. GRDC Grain Storage Fact Sheet, June 2013, <http://www.grdc.com.au/GRDC-FS-GrainStoragePestControl>

<sup>11</sup> P Burrill, P Botta, C Newman (2010) Aeration cooling for pest control. GRDC Grain Storage Fact Sheet, September 2010, <http://www.grdc.com.au/~media/AB8938CFDCCC4811AD218B45C308BEED.pdf>

- Sample from the top and bottom of grain stores for early pest detection. Insect probe or pitfall traps installed in the top of the grain store will often show insect activity before they are seen on the surface of the grain.
- Sieve samples onto a white tray to make small insects easier to see. Sieves should be of 2-mm mesh and need to hold at least 1 L of grain. Hold the tray in the sunlight. This warms insects and encourages movement, making pests easier to see.
- To help identify live grain pests, place them into a clean glass container at >20°C to encourage activity without overheating or killing them. Weevils and saw-toothed grain beetles can walk up the walls of the glass easily, but flour beetles and lesser grain borer cannot. Look closely at the insects walking up the glass— weevils have a curved snout at the front and saw-toothed grain beetles do not.<sup>12</sup>

Recent research in southern and central Queensland has shown that industry may need to consider an area-wide approach to pest and resistance management. The research studied the flight dispersal by the lesser grain borer and the rust-red flour beetle and involved setting beetle traps along a 30-km transect in the Emerald district. It showed that the lesser grain borer flies all year round in central Queensland, whereas the flour beetle appeared to be located mainly around storages during the winter months, spreading into the surrounding district in summer. This study highlights the importance of finding and dealing with infestations in storages and any dumps of old grain to limit the number of pests that can infest clean grain.

NOTE: Exotic pests including Khapra beetle (*Trogoderma granarium*) and the fungal disease Karnal bunt (*Tilletia indica*) are a threat to the Australian grains industry— report sightings immediately.

Grain Storage Information Hotline: 1800 WEEVIL (1800 933 845) will put you in contact with your nearest grain storage specialist.

## 13.5 Grain protectants and fumigants

Before using a new grain protectant or fumigant, growers are advised to check with prospective buyers, as the use of some chemical may exclude grain from certain markets.

### 13.5.1 Grain protectants

Grain protectants are one of many management tools for preventing pests in stored grain and have a particular role in unsealed storage and seed storage.

#### Key points

- Consider using grain protectants when gas-tight sealable storage is not available and to ensure security of planting seed.
- Grain protectants work best when combined with meticulous storage hygiene and aeration cooling.
- Stringent maximum residue limits (MRLs) leave no margin for error in application. Always check with your grain buyer before applying.
- Even coverage is required to reliably manage stored grain insects.

#### Pest prevention

Grain protectants are designed to prevent pest infestations and not to control existing infestations. Grain must be clean and free of pests before applying a protectant. A common misunderstanding is that grain protectants kill insects already infesting the grain, but those types of products (contact disinfectants) are no longer available for on-farm use.

<sup>12</sup> P Burrill, P Botta, C Newman, B White, C Warrick (2013) Northern and southern regions stored grain pests—Identification. Grain Storage Fact Sheet, June 2013, <http://www.grdc.com.au/GRDC-FS-StoredGrainPestID>



In order to give protectants the best chance to defend stored grain, combine their use with meticulous storage hygiene practices before and after harvest. Cleaning up the storage site and the harvesting equipment removes harbours where pests can survive, ready to infest the new season's grain.

The addition of aeration cooling also provides an unattractive environment for pests in stored grain.

### Read the label

Always read the chemical label before choosing a protectant to ensure it is registered for use on the grain you wish to apply it to and will target the main insects commonly found in your storage (Table 3). As a general guide, most protectants are only registered for use on cereal grains, except malting barley, rice and maize.

The lesser grain borer (*Rhyzopertha dominica*) is the toughest of the common grain storage pests to deter with protectants, with only two products currently available — K-Obiol® and Conserve On-Farm™ (under permit PER14362).

To prolong the working life of these two products, alternate their use each year or two to avoid pests developing resistance to them.

**Table 3: Northern and southern region stored grain protectants guide.**

Treatments	Lesser grain borer ( <i>Rhyzopertha dominica</i> )	Rust-red flour beetle ( <i>Tribolium castaneum</i> )	Rice weevil ( <i>Sitophilus oryzae</i> )	Saw-toothed grain beetle ( <i>Oryzaephilus surinamensis</i> )	Flat grain beetle ( <i>Cryptolestes ferrugineus</i> )
Pirimiphos-methyl eg Actellic 900®					
Fenitrothion eg Fenitrothion 1000®					
Chlorpyrifos-methyl eg Reldan Grain Protector®					
Chlorpyrifos-methyl + S-methoprene eg Reldan Plus IGR®					
Deltamethrin + Piperonyl Butoxide eg K-Obiol® <sup>1</sup>					
Spinosad + Chlorpyrifos-methyl + S-methoprene eg Conserve On-Farm™					

■ Effective control  
■ Resistance widespread (unlikely to be effective)  
■ Not registered for this pest

<sup>1</sup> Approved user ID card required for purchase — contact Bayer to obtain ID.

Source: APVMA

### Close to MRL

As grain markets have become less tolerant to protectants and maximum residue limits (MRLs) are monitored scrupulously, accurate application is essential. Some of the protectants, even if used at the recommended label rate, are right on the MRL leaving no room for error in applying the correct rate and even spread.

Commodity vendor declarations are also used in many cases to ensure a parcel of grain is only subjected to one application of the protectant to avoid exceeding the MRL.

### Accurate application

Always follow label directions, but as an example some protectants are applied at a rate of one litre of mixed product per tonne of grain. To achieve even coating of the grain best results are achieved with one, or even better with two, flat fan nozzles mounted to spray into the auger as the grain is loaded into storage. Mixing 1 L/t is not easy and relies on agitation as the grain passes up the auger.

Applying protectants in a belt conveyor does not provide adequate mixing and even coating. Spray can also cause issues with the belt slipping on drive rollers.



Some conveyor manufacturers offer a separate application kit — ensure it can apply the protectant evenly to the stream of grain and includes agitation to mix the product through the grain.

Some protectants start deteriorating 48 hours after being mixed with water so avoid leaving for long periods before applying to grain. The product label will also indicate the anticipated effective life of the protectant on the grain.

The effective life of protectants is shortened if applied to grain above 12% moisture content (MC) and above 27°C or is exposed to direct sunlight, such as the end of a shed or an open bunker.<sup>13</sup>

**i MORE INFORMATION**

[Phosphine alternatives still a stored grain protection goal](#)

[GRDC Grain Industry Guide: Fumigating with phosphine, other fumigants and controlled atmospheres. Do it right—do it once](#)

[Killing storage pests without mercy](#)

GRDC Podcast: [Phosphine Resistance](#)

### 13.5.2 Grain fumigation

In order to kill grain pests at all stages of their life cycle (egg, larva, pupa, adult), phosphine gas needs to reach, and be maintained at, a concentration possible only in a gas-tight storage.

**Key points**

- To control insects at all life stages the only option is to fumigate in a gas-tight storage.
- Cool grain temperatures require a longer fumigation period.
- Aeration fans fitted on gas-tight silos provide a number of benefits including a shorter ventilation period following a fumigation.

The total time required for effective fumigation ranges from 10–17 days, accounting for the minimum exposure period, ventilation and withholding period. This highlights the importance of monitoring grain regularly and at least 17 days before out-loading to allow sufficient time to fumigate if required.

**Rates for success**

When determining how much phosphine to apply, it is important to treat the entire storage volume, regardless of how much grain is contained inside (Table 4). For example, a 100 tonne silo full of grain requires 200 phosphine tablets. If that same 100 t silo is only half full of grain, it still requires 200 phosphine tablets for effective fumigation.

**Table 4:** Application rates for phosphine tablets in storage.

Storage capacity		Number of tablets required
Tonnes wheat	Cubic metres	
1	1.3	2
50	65	100 (1 tin)
100	130	200 (2 tins)
200	260	400 (4 tins)
300	400	600 (6 tins)

Source: Nufam

**Handle with care**

Phosphine is a highly toxic gas with potentially fatal consequences if handled incorrectly. As a minimum requirement, the label directs the use of cotton overalls buttoned at the neck and wrist, eye protection, elbow-length PVC gloves and a breathing respirator with combined dust and gas cartridge.

<sup>13</sup> GRDC (2015) Grain protectants prevent pests. Grain storage Fact Sheet, <http://www.grdc.com.au/GRDC-FS-GrainStoragePestControl>



### Where to apply

Arrange the tablets where as much surface area as possible is exposed to air, so the gas can disperse freely throughout the grain stack.

Spread phosphine tablets evenly across trays before hanging them in the head space or placing them level on the grain surface inside a gas-tight, sealed silo.

Hang bag chains in the head space or roll out flat on the top of the grain so air can freely pass around them as the gas dissipates.

Bottom-application facilities must have a passive or active air circulation system to carry the phosphine gas out of the confined space as it evolves. Without air movement, phosphine can reach explosive levels if left to evolve in a confined space.

### Time to kill

To control pests at all life stages and prevent insect resistance, phosphine gas concentration needs to reach 300 parts per million (ppm) for seven days (when grain is above 25°C) or 200 ppm for 10 days (between 15–25°C). Insect activity is slower in cooler grain temperatures so require longer exposure to the gas to receive a lethal dose.

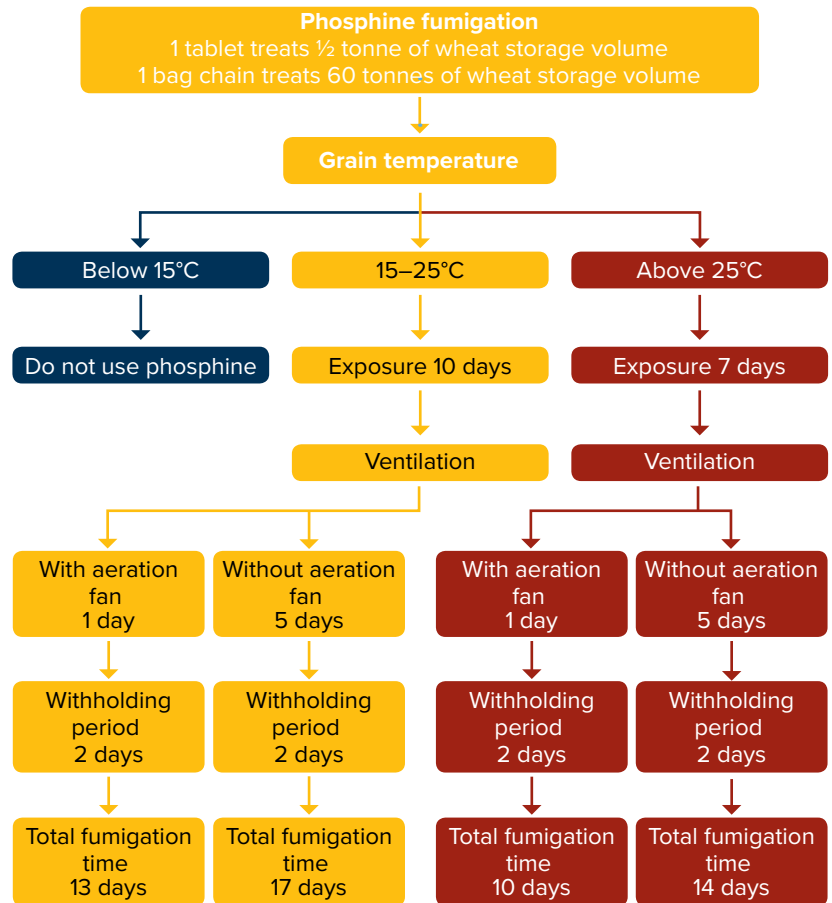
### Gas venting

Following fumigation, ventilate silos so grain can be delivered free from harmful gas residues.

With tablet residue or bag chains removed, leave silos open for no less than five days, or no less than one day with aeration fans operating.

The final step is to hold grain for a further two days after ventilation before using for human consumption or stockfeed (Figure 6).<sup>14</sup>

<sup>14</sup> GRDC (2014) Grain fumigation – a guide. Grain storage Fact Sheet, <http://www.grdc.com.au/GRDC-FS-GrainFumigationGuide>



**Figure 6:** Phosphine fumigation period.

### Phosphine resistance

Resistant pests survive because the genes that cause phosphine resistance slow the rate of toxin production. As a result, phosphine in resistant insects takes a lot longer to work.

Increasing the concentration of gas will not result in resistant insects being reliably killed by short fumigations. However, a high enough concentration over a long fumigation will control resistant insects. This has been the case in the past when a label change led to an increase in the dose applied.

Although it takes longer to kill resistant pests, phosphine attacks pests in such a way that it is very unlikely that pests will ever become completely immune.<sup>15</sup>

#### Delaying resistance

Resistance to phosphine, although widespread geographically, is still infrequent among the beetles on a typical farm.

Although poor fumigation will kill some or most insects in a silo, when poor fumigations are repeated on the same parcel of infested grain, resistant insects become abundant and pest control is more difficult.

<sup>15</sup> A Ridley, D Schlipalius (2015) Effective phosphine fumigation takes time. Ground Cover Issue 119, Nov-Dec 2015, <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-119-Nov-Dec-2015/Effective-phosphine-fumigation-takes-time>

Phosphine is a small molecule and is roughly the same density as air. It is easy for phosphine to escape from an unsealed silo. Silo design and build quality are critical to obtaining a suitable seal to contain phosphine.

Short fumigations are unlikely to kill resistant insects; so effective phosphine fumigations require a high concentration of gas to be maintained for the correct number of days. This requires a silo that meets the AS2628 standard.

Failing to use a gas-tight silo will mean the gas escapes (no matter how many tablets are used) before enough damage has been done to kill all of the pests. Growers need to insist that any new silo used to fumigate insects meets the Australian Standard and this is noted in the sales contract.<sup>16</sup>

### What alternative fumigants are available?

ProFume® and VaporMate® are available alternatives to phosphine, however they can only be applied by a licensed fumigator.

Carbon dioxide and nitrogen are 'controlled atmosphere' alternatives to phosphine which can be done by anyone providing they have access to the required equipment and knowledge. All of these alternatives require a gas-tight storage for successful control of insects and are currently more expensive than phosphine.<sup>17</sup>

For more information see the back pages of [Fumigating with phosphine, other fumigants and controlled atmospheres](#)

<sup>16</sup> A Ridley, D Schlipalius (2015) Effective phosphine fumigation takes time. Ground Cover Issue 119, Nov-Dec 2015, <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-119-Nov-Dec-2015/Effective-phosphine-fumigation-takes-time>

<sup>17</sup> GRDC Stored Grain Information Hub (2017) What alternative fumigants are available? <http://storedgrain.com.au/what-alternative-fumigants-are-available/>

 MORE INFORMATION

CJ Birch *et al.* (2003) Agronomy of maize in Australia—in review and prospect. In 5th Australian Maize Conference.

## Environmental issues

The optimum temperature for maize growth and development is 18°–32°C, with temperatures of ≥35°C considered inhibitory. The optimum soil temperatures for germination and early seedling growth are ≥12°C, and at tasselling 21°–30°C is ideal.

Maize is grown globally from 50°N to 40°S, and from sea level up to 4000 m altitude. Maize is a short-day plant, with 12.5 h/day suggested as the critical photoperiod. Photoperiods longer than this may increase the total number of leaves produced prior to initiation of tasselling, and may increase the time taken from emergence to tassel initiation (Birch 1997).<sup>1</sup>

### 14.1 Frost issues

Low autumn temperatures can kill maize tissue before the plant reaches maturity. When an early autumn frost occurs, maize growers need to know the impact of the damage on hybrid maturity and yield. The technical bulletin [Autumn frosted maize crops](#) provides information on the effect of frost on maize, outlines options for handling frosted crops and discusses ways to reduce the risk of frost damage.<sup>2</sup>

#### 14.1.1 Conditions causing frost damage

The severity of frost damage will depend largely on the duration and extent of freezing temperatures. Substantial frost damage of leaf, stalk and stem tissue may occur if temperatures drop below 0°C for 4–5 h or when temperature drops to –2°C or less for even a few minutes. Frost damage due to rapid heat loss from within the crop can occur when temperatures are several degrees above zero if the air is clear and still. Under these circumstances, leaf temperatures can drop below the actual air temperature.

When air temperature is close to freezing, frosting can occur in low-lying areas, where the cold air tends to accumulate. Higher areas within the same paddock may not sustain any frost damage. A dense maize crop can trap considerable warmth within its canopy. Outer rows and areas of paddocks that have low plant populations are more frost-prone.

Maize plant parts vary in susceptibility to frost damage. Leaves are most susceptible because their thinness makes it difficult for them to hold heat. Thicker plant tissues such as stalks, husks and grain have greater heat-retention capabilities.<sup>3</sup>

#### 14.1.2 Assessing frost damage

A visual inspection of frost-damaged maize should be made the morning after the frost, after the sun has risen and the crop has begun to thaw. At this time, damaged tissue will begin to wither and cell contents will be released as a sugary coating on the leaves and stem.

When assessing the crop, take into account the number of leaves that have been frosted, cob or stalk damage, and the proportion of the paddock that has been affected. It is important to assess the stage of maturity of the crop in terms of how far the crop was from harvest when it was frosted. Outer rows and any hollows in the

<sup>1</sup> S Belfield, C Brown (2008) Field crop manual: maize. A guide to upland production in Cambodia. Cambodian Agricultural Research and Development Institute and NSW Department of Primary Industries, <http://aciar.gov.au/files/node/8919/maize%20manual%2072dpi.pdf>

<sup>2</sup> Autumn frosted maize crops. Technical Insights, Pioneer Brand Products, <http://www.pioneer.co.nz/maize-grain/product-information/grain-technical-insights/autumn-frosted-maize-crops.html>

<sup>3</sup> Autumn frosted maize crops. Technical Insights, Pioneer Brand Products, <http://www.pioneer.co.nz/maize-grain/product-information/grain-technical-insights/autumn-frosted-maize-crops.html>

**i MORE INFORMATION**

[Autumn frosted maize crops. Technical Insights. Pioneer Brand Products.](#)

[Frost. Corn Agronomy. University of Wisconsin.](#)

[M DeVries, AS Goggi. Seed quality tests for early detection of fall frost damage in immature maize seed.](#)

[Frost risk for maize silage grown in South Canterbury. Foundation for Arable Research.](#)

[Increasing maize resistance to lodging and frost. Crop Nutrition. Yara UK.](#)

[K Pembleton, RP Rawnsley \(2012\). Frost risk associated with growing maize for silage on Tasmanian dairy farms. Australian Agronomy Conference.](#)

[Assessing frost risk for silage maize. Programs. Tasmanian Institute for Agriculture.](#)



crop are likely to be more affected by frost than the rest of the crop. Always walk well into and through the crop to make an accurate assessment of damage. Generally, warmer air is entrapped in the main body of the crop and the initial frost does not penetrate the crop canopy as far. <sup>4</sup>

The effect of a frost on grain yield is determined by the amount of leaf that is killed and the stage of development when the frost occurs. The closer the plant is to black layer, the lower the yield loss caused by a frost. Even if all of the leaves are killed, the plant can continue to mature as sugars are mobilised from the stalks to the ear. Grain dry weight will continue to increase up until black layer as long as there are leaves (especially above the ear) or even if just the stalk and the husk cover are still green. If there are several days of cool temperatures (7°–12°C) during grainfill, premature black layer may occur and grainfill will cease. This can happen even without a frost.

The potential grain loss from an autumn frost at different stages of grain development is shown in Table 1.

**Table 1: Potential losses in maize grain yield after frost.**

Corn development stage	Killing frost (leaves and stalks)	Light frost (leaves only)
	Percent yield loss	
1/3 Milk-line	55	35
_ Milk-line	40	25
2/3 Milk-line	12	5
Black layer	0	0

Adapted from JJ Afuakwa, RK Crookston (1984) Using the kernel milk-line to visually monitor grain maturity in maize. Crop Science 24, 687–691

Grain crops frosted prior to milk-line will have a low grain yield potential and the kernels will be chaffy. It is recommended that these crops be kept for maize silage and left to mature to silage harvest dry matter (as outlined above).

When a grain crop is frosted at milk-line, the yields will be reduced by 50% unless some leaves survived the frost (Table 1). Severely frosted crops will need to be field-dried, and this will result in high field losses, because maize that is frosted at an immature stage tends to have a greater incidence of stalk breakage. Ear moulds may develop when drying is slow and test weight is likely to be low. During combining, grain will be susceptible to breakage and the wet core may break into several pieces, increasing the risk of grain rejection or discounting due to broken grain and foreign material. For many crops that are frosted prior to ½ milk-line, maize silage is the best option.

Maize grain crops that are killed by frost after ½ milk-line will have reduced yield (Table 1) and test weights will be below normal. If only a portion of the plant tissue is killed and if the grain was close to black layer, the yield loss will be small and test weights will be closer to normal.

Studies in Minnesota simulating frost at milk-line (~55% grain moisture) indicated that immature maize killed by a frost dried normally when environmental conditions were favourable. The dry down was delayed for a few days after the frost, and this resulted in 4–9 more days to reach a harvest moisture level of 22–30% compared with non-frosted maize. This will delay harvest and/or increase drying charges.

Severe frost will not affect grain yield or quality after physiological maturity (black layer). <sup>5</sup> This is unlikely under Australian conditions.

<sup>4</sup> Autumn frosted maize crops. Technical Insights. Pioneer Brand Products. <http://www.pioneer.co.nz/maize-grain/product-information/grain-technical-insights/autumn-frosted-maize-crops.html>

<sup>5</sup> Autumn frosted maize crops. Technical Insights. Pioneer Brand Products. <http://www.pioneer.co.nz/maize-grain/product-information/grain-technical-insights/autumn-frosted-maize-crops.html>





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### 14.1.3 Risk management for frost

The variability in the incidence and severity of frost means that growers need to adopt a number of strategies as part of their farm management plan. These include pre-season, in-season, and post-frost strategies.<sup>6</sup>

See GRDC Tips and Tactics [Managing frost risk](#) for general principles of establishing a frost management plan.

Growers need to consider carefully whether earlier sowing is justified in seasons where warmer temperatures are predicted. Warmer temperatures may reduce the frequency of frost events but also increase the rate of crop development bringing crops to the susceptible, post heading stages earlier.<sup>7</sup>

### 14.1.4 The changing nature of frost in Australia

The length of the frost season has increased across much of the Australian grainbelt by between 10 and 55 days between 1960 and 2011. In some parts of eastern Australia, the number of frost events has increased.

CSIRO analysis of climate data over this period suggests the increasing frost incidence is due to the southerly displacement and intensification of high pressure systems (subtropical ridges) and to heightened dry atmospheric conditions associated with more frequent El Niño conditions during this period.

The southern shifting highs bring air masses from further south than in the past. This air is very cold and contributes to frost conditions.

In the eastern Australian grainbelt the window of frost occurrence has broadened, so frosts are occurring both earlier and much later in the season. In the Western Australian grainbelt there are fewer earlier frosts and a shift to frosts later into the season.

The frost window has lengthened by three weeks in the Victorian grainbelt and by two weeks in the NSW grainbelt. The frost window in Western Australia and Queensland has remained the same length, while sites in eastern South Australia are similar to Victoria and sites in western South Australia are more like Western Australia. Northern Victoria seems to be the epicentre of the change in frost occurrence, with some locations experiencing a broadening of the frost season by 53 days.<sup>8</sup>

## 14.2 Waterlogging and flooding issues

In generating a yield response to applied water, it is as important to avoid waterlogging stress as it is to avoid stress from moisture deficits.<sup>9</sup>

In addition, loss of N can result from waterlogging and heavy rains, such as those received in parts of the northern region in January 2013 that resulted in soil N losses of 10–20 kg/ha, on average, through denitrification from summer mineralised N. Soil test results showed soil profiles with low levels of mineral N.

If heavy rains waterlog the soil during hot conditions when soil nitrate concentrations are high, such as at the end of a fallow or before fertiliser N has been taken up by the crop, denitrification losses can be large for summer crops such as maize.

In January and February 2013, trials at Tamworth and Quirindi, NSW, showed significant losses of nitrous oxide from crops sown late in 2012 that experienced little early rain after sowing.

6 GRDC (2016) Managing frost risk. Northern, Southern and Western Regions. GRDC Tips and Tactics, <http://www.grdc.com.au/ManagingFrostRisk>

7 J Christopher, B Zheng, S Chapman, A Borrell, T Frederiks, K Chenu (2016) An analysis of frost impact plus guidelines to reduce frost risk and assess frost damage. GRDC Update Papers 20 July 2016, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/An-analysis-of-frost-impact-plus-guidelines-to-reduce-frost-risk-and-assess-frost-damage>

8 GRDC (2016) Managing frost risk. Northern, Southern and Western Regions. GRDC Tips and Tactics, <http://www.grdc.com.au/ManagingFrostRisk>

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Other trials at Tamworth showed that significant denitrification occurred in summer after post-harvest mineralisation of N-rich crops such as chickpeas and canola.<sup>10</sup>

### 14.2.1 Effects on the maize root system

Effects of soil drought or waterlogging on morphological traits of the root system and internal root anatomy of the seminal root have been studied in maize hybrids of different drought tolerance. The results demonstrated a broad variation in the habit of the root system and in some anatomical properties.<sup>11</sup>

Plants grown under waterlogging or drought conditions showed a smaller number and less dry matter of lateral branching roots than plants grown in control conditions. Waterlogging was more harmful to the growth of roots and had a greater effect on internal root anatomical characteristics than drought. The observed effects of both treatments were greater in drought-sensitive hybrid Pioneer D than in drought-resistant hybrid Pioneer C. Pioneer C had more extensive rooting and smaller alterations in root morphology caused by the stress conditions. Differences between the resistant and sensitive maize hybrids were apparent for the examined root anatomical traits. Results confirm that the hybrid Pioneer D, with high drought susceptibility, was also more sensitive to periodic soil water excess. More efficient water use and a lower shoot to root ratio were found to be major reasons for the higher stress resistance of the hybrid Pioneer C.

The different response of the examined hybrids to the conditions of drought or waterlogging may be explained by a more economical water balance and more favourable relations between the shoot and root dimensions in the drought-resistant genotype. The observed modifications of the internal root structure caused by water deficit in plant tissues may influence water conductivity and transport within roots.

Morphological and anatomical traits of the maize root system may be used as selection criteria in maize breeding.<sup>12</sup>

<sup>10</sup> T Dixon (2014) Denitrification the latest chapter in the N story. *Ground Cover* Issue 108, Jan, Feb, 2014, GRDC, <http://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-108-Jan-Feb-2014/Denitrification-the-latest-chapter-in-the-N-story>

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**i MORE INFORMATION**

[Market research lifts export ambitions](#)

**i MORE INFORMATION**

[Grain Trade Australia \(2016\) Maize trading standards. 2016/17 season.](#)

# Marketing

Maize is renowned for its flexibility and variety of end uses; however, it remains necessary for maize growers to plan their marketing strategies well in advance, because demand for Australian maize relies heavily on domestic markets (Figure 1). All maize surplus to the requirements of human consumption markets must be valued against other feed grains such as wheat, barley and, in particular, sorghum. Proximity to markets has a major influence on profitability, particularly of silage.

The processors of maize grain for the human consumption markets have stringent guidelines that must be understood by growers entering the industry. Forward contracts are used extensively by processors to ensure reliability of supply and grain quality. Contracts may outline the hybrids to be grown, which may not necessarily be the highest yielding lines for the region; however, premiums may be offered based on quality. Traditional maize growers tend to be offered contracts ahead of new growers, making initial contracts difficult to attain. In most irrigation areas, it is considered high risk to plant a maize crop without a major portion under contract.



**Figure 1:** It is important for maize growers to plan marketing in advance.

Photo: Nicole Baxter

The popcorn market is especially small and volatile, and as such, all product is bought domestically under contract.

Forward contracting is also common in the dairy and feedlotting industries for the purchase of maize silage. Contracts will specify quantity and quality parameters and the date of delivery. Growers must consider the risk of crop contamination from spray drift when growing maize under contract, because detection of residues will result in product rejection. Usually, the grower organises harvest and transport, which is paid for by the buyer.

 **MORE INFORMATION**

Go to [Maize Association of Australia](#) to download supply chain and export protocols, together with detailed information on how to reduce the risk of contamination when growing maize.<sup>2</sup>

## 15.1 Preventing mycotoxin contamination

Mycotoxins are toxic chemicals that can be produced by some fungi when they infect maize. Mycotoxins are associated with diseases in humans, pets and livestock, and so their presence in maize is regulated in domestic and international markets. Australian maize is generally of high quality with regard to mycotoxin contamination compared with other exporting countries, yet there have been recent trade problems, with containers of maize failing to meet mycotoxin standards upon arrival. It is unclear whether contamination occurred at the source or during storage and transport. Despite only a small percentage of Australian maize ever having been affected, these incidents have highlighted the need for an industry-wide approach to ensure that Australian maize meets the standards of all end-users.

The Maize Association of Australia is establishing supply chain and export protocols to enhance the reputation of Australian maize. The protocols highlight steps that should be taken by exporters to ensure that shipments meet international standards.<sup>1</sup>

## 15.2 Marketing

### 15.2.1 Grain

Selling is done through normal merchant channels or under contract to millers, starch manufacturers, or corn chip or breakfast cereal manufacturers. Price premiums apply for grain of various processing qualities. The feed market tends to have lower prices, but enjoys much more flexibility with regard to the range of hybrids used, allowing growers to make use of higher yielding hybrids.<sup>3</sup>

### 15.2.2 Marketing silage

Silage maize is normally sold direct to feedlots and dairies at an agreed price per tonne in-field. Farmers growing for stockfeed grain and silage need to be aware of the stringent requirement of most buyers in relation to chemical residues.<sup>4</sup>

### 15.2.3 Drying corn for the gritting millers

Hairline (stress) cracking of corn kernels must be within limits prescribed by millers. Stress cracks are cracks in the clear endosperm inside the kernel, which do not rupture the seed coat.

The following points on drying may also help growers to minimise stress cracking and obtain high gritting-quality corn:

- Starting grain moisture levels >17.5% make drying very risky for hairline cracking.
- Ensure that grain temperature does not exceed 38°C during drying.
- Cool the dried grain slowly. Avoid using blowers on grain after drying on cool, windy days. Dry grain early in the day to enable slow cooling as the day temperature slowly decreases. Drying grain under heat until late afternoon will mean that the hot grain is too rapidly cooled, often resulting in excessive cracking.
- Do not leave grain uncovered overnight in field bins or open dryers. Rain or dew will predispose surface grain to cracking.

<sup>1</sup> N Moore, L Serafin, L Jenkins (2014) Summer crop production guide 2014. NSW DPI Management Guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide>

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[GRDC—Driving Agronomy Podcasts.](#)

## MORE INFORMATION

[Maize Association of Australia.](#)

- ‘Dryeration’ and combination drying systems minimise stress cracking. Dryeration involves a rapid initial drying followed by 6–10 h of tempering to relieve stresses, then a final cooling period. Combination or two-stage drying uses a first phase of high-temperature, high-speed drying, followed by a second final drying with ambient or low-temperature air.<sup>5</sup>

### 15.3 Maize Association of Australia (MAA)

The MAA was established in 1991 and aims to address the needs of all sectors of the Australian maize industry. The aims of the MAA are to:

- promote the exchange of ideas, knowledge, innovation and cooperation of all parties in the maize industry, from primary producer to exporter;
- support the production, development and marketing of maize products;
- increase the awareness of maize, its uses and its byproducts; and
- increase the communication between growers and end-users to promote and increase the many uses of maize.

<sup>5</sup> QDAF (2012) Harvesting and marketing for maize. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/maize/harvesting-marketing>



# Current research

## Project Summaries

### [www.grdc.com.au/ProjectSummaries](http://www.grdc.com.au/ProjectSummaries)

As part of a continuous investment cycle each year the Grains Research and Development Corporation (GRDC) invests in several hundred research, development and extension and capacity building projects. To raise awareness of these investments the GRDC has made available summaries of these projects.

These project summaries have been compiled by GRDC's research partners with the aim of raising awareness of the research activities each project investment.

The GRDC's project summaries portfolio is dynamic: presenting information on current projects, projects that have concluded and new projects which have commenced. It is updated on a regular basis.

The search function allows project summaries to be searched by keywords, project title, project number, theme or by GRDC region (i.e. Northern, Southern or Western Region).

Where a project has been completed and a final report has been submitted and approved a link to a summary of the project's final report appears at the top of the page.

The link to Project Summaries is [www.grdc.com.au/ProjectSummaries](http://www.grdc.com.au/ProjectSummaries)

## Final Report Summaries

### [http://finalreports.grdc.com.au/final\\_reports](http://finalreports.grdc.com.au/final_reports)

In the interests of raising awareness of GRDC's investments among growers, advisers and other stakeholders, the GRDC has available final reports summaries of projects.

These reports are written by GRDC research partners and are intended to communicate a useful summary as well as present findings of the research activities from each project investment.

The GRDC's project portfolio is dynamic with projects concluding on a regular basis.

In the final report summaries there is a search function that allows the summaries to be searched by keywords, project title, project number, theme or GRDC Regions. The advanced options also enables a report to be searched by recently added, most popular, map or just browse by agro-ecological zones.

The link to the Final Report Summaries is [http://finalreports.grdc.com.au/final\\_reports](http://finalreports.grdc.com.au/final_reports)

## Online Farm Trials

### <http://www.farmtrials.com.au/>

The Online Farm Trials project brings national grains research data and information directly to the grower, agronomist, researcher and grain industry community through innovative online technology. Online Farm Trials is designed to provide growers with the information they need to improve the productivity and sustainability of their farming enterprises.

Using specifically developed research applications, users are able to search the Online Farm Trials database to find a wide range of individual trial reports, project

summary reports and other relevant trial research documents produced and supplied by Online Farm Trials contributors.

The Online Farm Trials website collaborates closely with grower groups, regional farming networks, research organisations and industry to bring a wide range of crop research datasets and literature into a fully accessible and open online digital repository.

Individual trial reports can also be accessed in the trial project information via the Trial Explorer.

The link to the Online Farm Trials is <http://www.farmtrials.com.au/>

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SECTION 17 MAIZE

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