



THE COST OF FROST

THE CAUSE AND EFFECT OF FROST ON GROWING GREAT GRAIN



GRDC

GRAINS RESEARCH
& DEVELOPMENT
CORPORATION

A TEACHING UNIT FOR
YEAR 10 AND 11
AGRICULTURE STUDENTS

About the GRDC

The GRDC

The Grains Research and Development Corporation is a statutory authority established to plan and invest in research, development and extension (RD&E) for the Australian grains industry.

Its primary objective is to drive the discovery, development and delivery of world-class innovation to enhance the productivity, profitability and sustainability of Australian grain growers and benefit the industry and the wider community.

Its primary business activity is the allocation and management of investment in grains RD&E.

GRDC Vision

A profitable and sustainable Australian grains industry, valued by the wider community.

GRDC Mission

Create value by driving the discovery, development and delivery of world-class innovation in the Australian grains industry.

GRDC Values

- We are committed and passionate about the Australian grains industry.
- We value creativity and innovation.
- We build strong relationships and partnerships based on mutual trust and respect.
- We act ethically and with integrity.
- We are transparent and accountable to our stakeholders.

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1.0 Teaching the science of grains



The Grains Research and Development Corporation has invested in the development of a suite of user-friendly grain education resources and initiatives for students, teachers and families.

These resources have been developed with teacher and researcher input and have been designed following a comprehensive survey of more than 340 teachers throughout Australia.

In each of our curriculum-linked resources we have incorporated a range of lesson plans which explore the latest science, technology, engineering, mathematics, nutrition, research and innovation in the Australian agricultural industry. You can use these resources as a unit or select components to complement your teaching plan.

By using an investigation and inquiry based approach, students will touch, try, taste and even smell the science of the Australian grains industry. It provides an ideal and relevant teaching context to engage students in food production.

Specifically, resources are available to address the food and fibre curriculum descriptors in geography, science, home economics and agriculture.

We hope you have fun teaching with these resources. Please contact us for more information.

Kind regards

The GRDC Education Team

2.0 Learning outcomes and curriculum links

About the cost of frost

Frost is a major problem in Australia, estimated to cost the grains industry \$360 million every year. Frost damage, particularly during grain fill, can damage the reproductive organs of the flower resulting in grain sterility. This in turn affects grain development resulting in less grain produced or lower yield and poorer grain quality. In recognition of this industry issue, the grains industry through the GRDC has invested significantly into research and development which will help farmers better manage frost. These R&D projects have included work into breeding frost tolerant varieties, using precision technologies to map frost prone regions and landscape variation, improved weather mapping and monitoring, understanding frost hot spots and looking at changing the time of seeding to alter the frost risk window. Overall, the use of science, engineering, mathematics and technologies are essential to help ensure farmers can produce high quality grains in frost prone areas.

Overview

This resource focuses on a major issue faced by Australian cropping farmers. Students gain an understanding of frost and its impacts on cereal crop and plant growth, reproductive development and overall grain quality and learn how technology can be used to monitor and manage frost.

Students will look at secondary resources to assess geographical maps and generate primary data on historical frost events, daily temperature fluctuations, impact of topography on frost and the role of plant breeding and research in helping farmers produce food crops in frost prone areas. Through practicals, students will gain inquiry skills and in extension, students will have the opportunity to explore farming innovation through programming and coding. Students make their own frost temperature sensor, use online applications and programs.

Curriculum focus

Students should be able to

- Organise and summarise geographical data, in particular weather information.
- Explain how geographical understanding of the environment can influence potential crop yield.
- Explore how technology can assist in scientific understanding of crop systems.
- Explore paddock practices and research through investigation.

3.0 Australian curriculum content descriptions

Science

Nature and the development of science

Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries (ACSHE192).

Use and influence of science

Advances in science and emerging sciences and technologies can significantly affect people's lives, including generating new career opportunities (ACSHE195).

Questioning and predicting

Formulate questions or hypotheses that can be investigated scientifically (ACSIS198).

Processing and analysing data and information

Analyse patterns and trends in data, including describing relationships between variables and identifying inconsistencies (ACSIS203).

Geography

Geographical knowledge and understanding

Environmental, economic and technological factors that influence crop yields in Australia and across the world (ACHGK062).

Collecting, recording, evaluating and representing

Collect, select, record and organise relevant data and geographical information, using ethical protocols, from a range of appropriate primary and secondary sources (ACHGS073).

Interpreting, analysing and concluding

Evaluate multi-variable data and other geographical information using qualitative and quantitative methods and digital and spatial technologies as appropriate to make generalisations and inferences, propose explanations for patterns, trends, relationships and anomalies, and predict outcomes (ACHGS076).

4.0 Teaching unit content and overview

This resource contains a range of curriculum-linked lesson plans which teachers can cut, paste, and utilise as they see fit. Our team work to develop resources which are interactive, fun and fit into your busy teaching schedule. The below table summarises the wide modes of engagement strategies including activity supported insights, exploring critical and lateral thinking and inquiry – use some of these lesson plans or all.

PAGE 10	5.0 Introduction Understanding the weather	<p>Accurately monitoring the weather is imperative to the success of food and fibre production in Australia. In the modern era, we can utilise innovative technology to make this efficient, accurate and provided in real-time. Use Understanding the weather in Australia to introduce the topic. Understanding the Australian timeline of weather monitoring knowledge and tools will assist students with understanding how farming practices have broadened.</p> <p>For more information about weather and climate please visit http://www.bom.gov.au/info/wwords/</p>
PAGE 13	6.0 Activity Weather and farming	<p>The role of the Bureau of Meteorology is introduced, with students asked to think about how forecasting governs on-farm practices.</p> <p>If your students are interested in how weather events occur and how high and low pressure systems affect our continent, check out this resource:</p> <p><i>ABC, 'How do high and low pressure systems work?' Professor Steven Siems, 2013</i> http://www.abc.net.au/science/articles/2013/01/31/3679358.htm</p>
PAGE 16	7.0 Activity Monitoring the weather on-farm: above and below the surface	<p>This case study provides students with the opportunity to assess real-world data from an Australian farm. Students are to analyse and interpret the graph provided and show their understanding by answering the questions.</p>
PAGE 18	8.0 Insight The cost of frost	<p>Introducing students to the focus on frost, this insight draws comparison between areas of frost across Australia and areas where we grow grain. Lead discussion from weather events which impact growing grains in Australia to focus on frost. Students are to explain how data, generated from platforms which utilise real-time and historical figures, can assist grain growers in decision making. They are to assess the graphs provided and provide a summary of their understanding.</p> <p>The National Frost Initiative was established in 2014 by the Grains Research and Development Corporation. This initiative focuses on research into plant genetics, management practices and environmental prediction. Find out more at www.grdc.com.au</p>
PAGE 20	9.0 Activity Frost watch!	<p>Students will require access to the internet so they can explore the risk of frost within their local area. They are to visit the Bureau of Meteorology website (www.bom.com.au) and explore the frost potential for your school's state and their local area. Alternatively, students could each be given a different area of the continent and report their summary back to the class.</p>
PAGE 21	10.0 Insight Frost through Australia	<p>Providing students with an understanding of the effect of frost at a ground level, this insight gives an understanding into the types of frost that occur and each corresponding weather condition.</p>

PAGE 23	11.0 Insight Frosty conditions	<p>To begin, students brainstorm how they think a frost event would affect a plant. Explore the different classifications of frost injury and discuss as a class.</p> <p>Students are to gain a simple understanding of plant development to appreciate how the level of frost risk correlates to not only the environmental climate conditions, but also the growth stage of the plant.</p> <p>Watch This video provides an overview of plant mechanisms. Grains Research and Development Corporation 'Plant Frost Mechanism with Glenn McDonald', 2015, https://www.youtube.com/watch?v=okKHYSV92FI</p>
PAGE 26	12.0 Practical Frosty plants	<p>Students will practice their scientific investigation skills in this practical and create environments which emulate those in growing grain. Discuss with students the limitations of this experiment in terms of recreating frost conditions as opposed to just freezing a plant. If the students are able, have them measure or control the temperature of the fridge/freezer.</p> <p>The practical provides a list of materials. Teachers may select the grain, pulse or canola seed variety which suits their teaching timeline. Teachers may wish to use freezers at school, or ask the students to complete care, practical research and application at home if possible, providing regular reports in class (note: be sure to practice best hygiene by ensuring freezers are not used for food). Depending on the variety chosen and the intervals at which measurements are chosen to be taken, teachers may have to provide students with multiple copies of the results table. This practical would suit pairs or groups.</p> <p>Watch This video provides an introduction to frost research in Australia. GCTV15: Frost Ratings, 2014, https://www.youtube.com/watch?v=zvBePYupXQM</p>
PAGE 32	13.0 Insight What's that frost?	<p>Using the table 'Stages and symptoms of frost' (previous page of resource), students are to assess the pictures of frost damage.</p> <p>Pictures include - tillering; burning of leaf tips, jointing/bending at stem, booting; spike trapped in boot, discolouration, heading and white heads. Can your students identify at which growth stage they think frost may have impacted the plant?</p> <p>Watch This video provides a background to screening and monitoring different varieties of wheat and barley for frost susceptibility. GCTV12: Frost Susceptibility, 2013, https://www.youtube.com/watch?v=AP_BKci-Zjw</p> <p>To show understanding, complete the brainstorm task A grower's frost management plan. Students should continue through the information answering the questions and openly discussing their understanding.</p>

PAGE 35	14.0 Activity Grain storm	Students are to make a connection between monitoring the weather and using the data generated from this monitoring in an effective way. This task requires students to compare two multi-variable graphs which illustrate the effect of sowing time, frost events and heat waves on potential yield outcomes. The table can be used to record their analysis.
PAGE 37	15.0 Activity Case study	<p>To begin, students are to read the article 'Late frosts cause southern concern' (Janet Paterson, Ground Cover Supplement April, 2014). http://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS109/Late-frosts-cause-southern-concern</p> <p>Students are to read this case study about a late frost event that occurred in 2013. They are to use their questioning skills to evaluate the information and explore the relationship between the variables by assessing graphs and maps.</p>
PAGE 41	16.0 Practical Technology for frost	<p>This task applies design and technology to agricultural studies with an aim of encouraging students to think about the technology needs on Australian grain farms.</p> <p><i>Material:</i> Students will need access to programming and coding kits to complete in class. There are several businesses that supply these kits to schools in Australia including STEMSEL Foundation. This resource has used STEMSEL temperature reader kits.</p> <p><i>*Alternatively, if your school does not have access to these types of kits, weather stations or digital temperature monitors can be easily adopted to this practical.</i></p>

5.0 INSIGHT

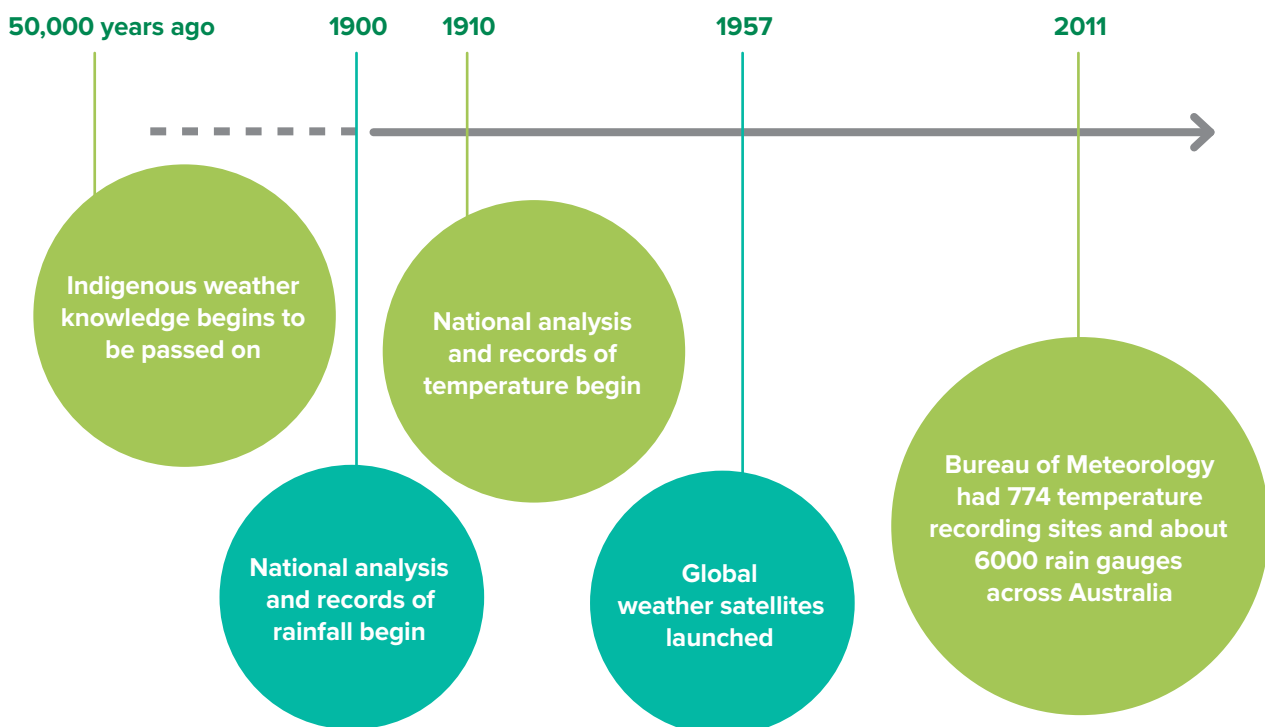
Understanding the weather in Australia

As a large country, Australia has many different seasons across its various climatic zones. DScientists and land owners are continuously researching these zones to understand history of the environment, impact of climate change, effectiveness of agriculture and more.

In the past and still today, the weather is monitored by examining changes in the surrounding environment e.g. changes in the colour of leaves, germination of plants, behaviour of animals, changes in wind and temperature. Modern weather is additionally monitored through the Bureau of Meteorology using a general Daily Weather Observations list, which records a number of weather elements. These include a daily minimum and maximum temperature, rainfall, strongest wind gust, evaporation, sunshine, humidity, wind, cloud and pressure is also recorded.

Overview

Monitoring and recording weather in Australia has been achieved through the use of Indigenous knowledge and engagement of modern practices such as those carried out by The Bureau of Meteorology



Information sourced from BOM

Did you know?

The Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT) dataset has been monitoring and collecting weather information from across Australia for more than 100 years!



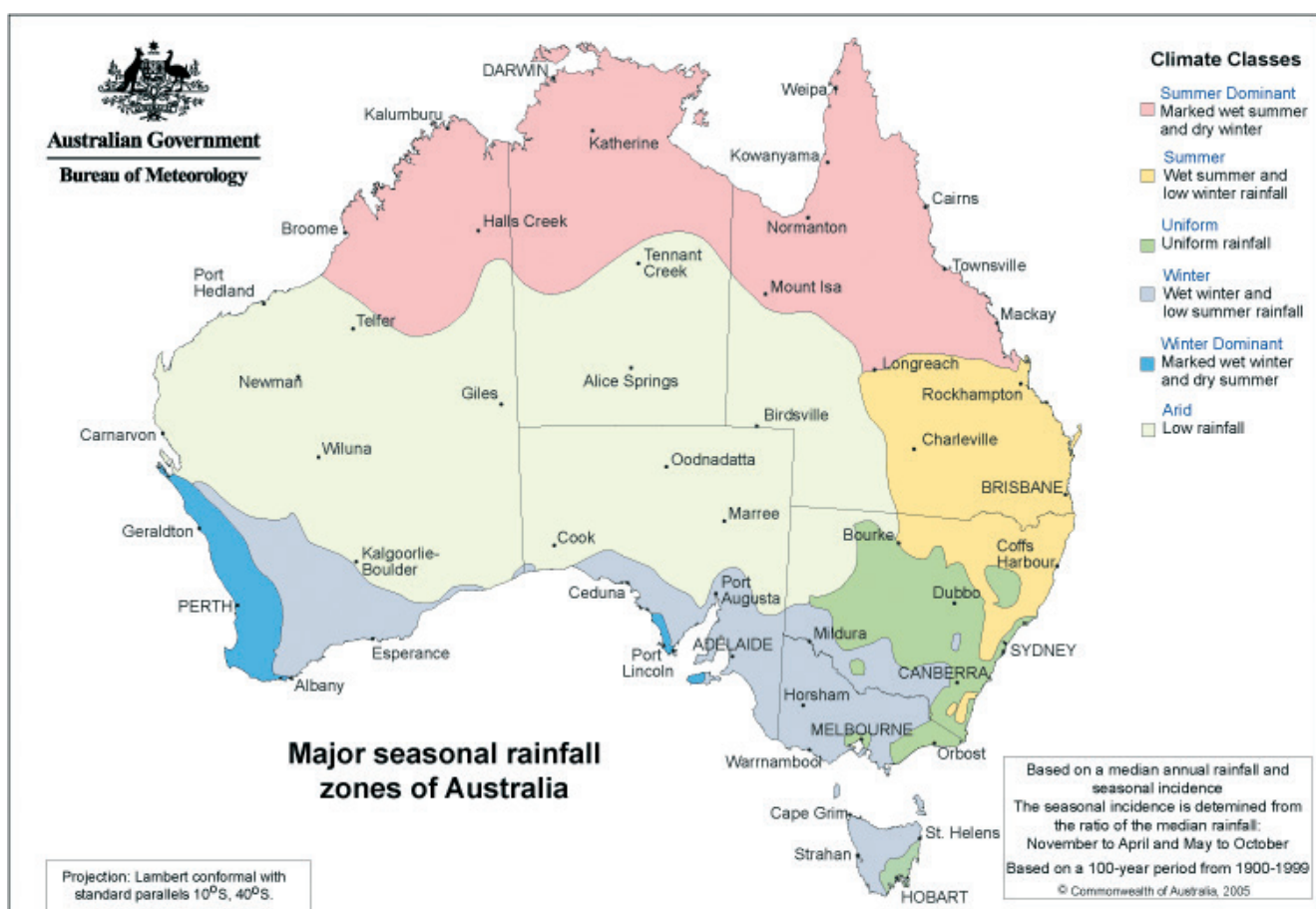


Did you know?

Australia's climate is largely determined by its latitude, with the mainland lying between 10 degrees south (°S) and 39°S and Tasmania extending south to 44°S.

Australia has many different climatic zones and seasonal calendars, from the tropical regions of the north to the arid expanses of the interior to the temperate regions of the south (ABS Year Book 2012).

"In northern Australia, temperatures are warm throughout the year, with a 'wet' season from approximately November through to April, when almost all the rainfall occurs, and a 'dry' season from May to October. Further south, temperature becomes more important in defining seasonal differences and rainfall is more evenly distributed throughout the year, reaching a marked winter peak in the south-west and along parts of the southern fringe' (ABS Year Book 2012). In these regions different climate classes are recognised which focus on rainfall.



Source: Bureau of Meteorology

Historic weather monitoring

Throughout time, Aboriginal knowledge of meteorology has been shared through storytelling, with seasonal descriptions established for each region of Australia which go beyond the European four seasons. For example, as shown in the table 'Indigenous weather knowledge', the Nyoongar people of Western Australia recognised six seasons. This is an example of the earliest understanding of our land and its weather systems. The table 'Contemporary farming seasonal calendar' is an example of the seasons used for monitoring and managing the growing of grains in Australia today. The Temperate Zone covers the south-west region of Western Australia, the south-eastern corner of South Australia, much of Victoria, Tasmania and much of New South Wales. These are the areas where grains and pulses are predominantly grown.

Indigenous weather knowledge – Nyoongar seasonal calendar

DECEMBER - JANUARY	FEBRUARY - MARCH	APRIL - MAY	JUNE - JULY	AUGUST - SEPTEMBER	OCTOBER - NOVEMBER
Birak	Bunuru	Djeran	Makuru	Djilba	Kambarang
Dry and hot	Hottest part of the year	Cooler weather begins	Coldest and wettest time of the year; more frequent gales and storms	Mixture of wet days with increasing number of clear, cold nights and pleasant warmer days	Longer dry periods

Source: BOM, Indigenous Weather Knowledge, 2014

Contemporary farming seasonal calendar – Major seasonal rainfall zones of Australia

DECEMBER - FEBRUARY	MARCH - MAY	JUNE - AUGUST	SEPTEMBER - NOVEMBER
Summer	Autumn	Winter	Spring
Dry and hot	Cooler weather begins	Cold and wet	Warmer weather begins

Activity:

What signs have you noticed that indicate changes in seasons in a) the southern region of Australia and b) the northern region of Australia?

6.0 ACTIVITY

Weather and farming



Want to know more?

ABC Science: 'Ask an expert' -
Professor Steven Siems

'How do high and low weather
systems work?'

The Bureau of Meteorology recognise that farmers across Australia rely on accurate weather information. They understand that access to weather data is critical for making daily decisions.

Through the BOM, the Natural Resource Management boards and a range of other providers, farmers have access to detailed live weather tracking, sets of historical data and a range of forecasting tools.

Farmers are keen to gain access to real-time weather which is specific to their property and therefore many are investing in on-farm weather stations. These stations, in combination with a range of online weather support tools, give them a unique insight into what they can expect on a daily, weekly and monthly basis. This is of great importance for growing food and fibre as the combination of forecasts and historical data helps inform everything from variety selection to time of sowing, to time of fertiliser or spray applications to time of harvest.

Meet Leighton Wilksch, a precision ag expert who installs on-farm weather stations in SA.

Leet says: "With growers concerned about the risks of farming with climate variability, many are now turning to technology to assist in their on-farm decision making. Since rainfall is one of the greatest variabilities and therefore risk factors on farms, growers need a sound understanding of how much and when rain is likely to fall... These on-farm weather stations give them real time information which can be downloaded straight from their phone."



GRAIN STORM

Why would weather forecasting be important for the following grain farming activities?



Weather and growing grains

There are many factors which pose a threat to the success of grain farming in Australia. These include diseases, pests, natural disasters, poor variety selection and weather events. Extreme weather events are a major risk faced by Australian farmers. In fact, they are considered a variable in that no one can control them.

Brainstorm

Think about what types of weather events occur in Australia and how we monitor their occurrence. Answer the following questions.



What types of weather events could potentially ruin a grain crop and how?

List different ways that the weather can be monitored. Do you know how these work?

Farmers often review weather maps to determine what conditions they may face over the coming days, weeks and months. The following maps are provided as part of the Bureau of Meteorology's website.

Discuss what information each map presents and why this is relevant to Australian farmers.

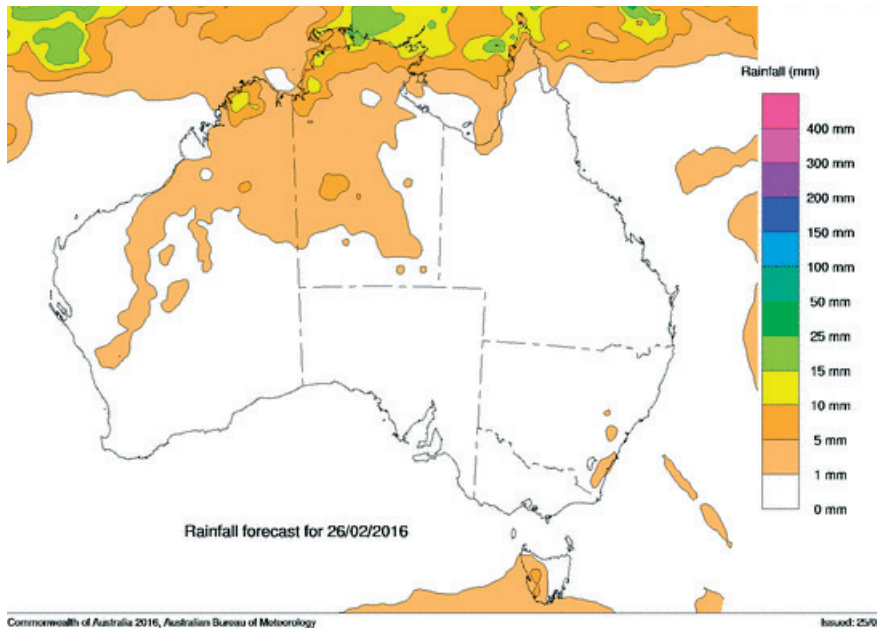


Image sourced from www.bom.gov.au

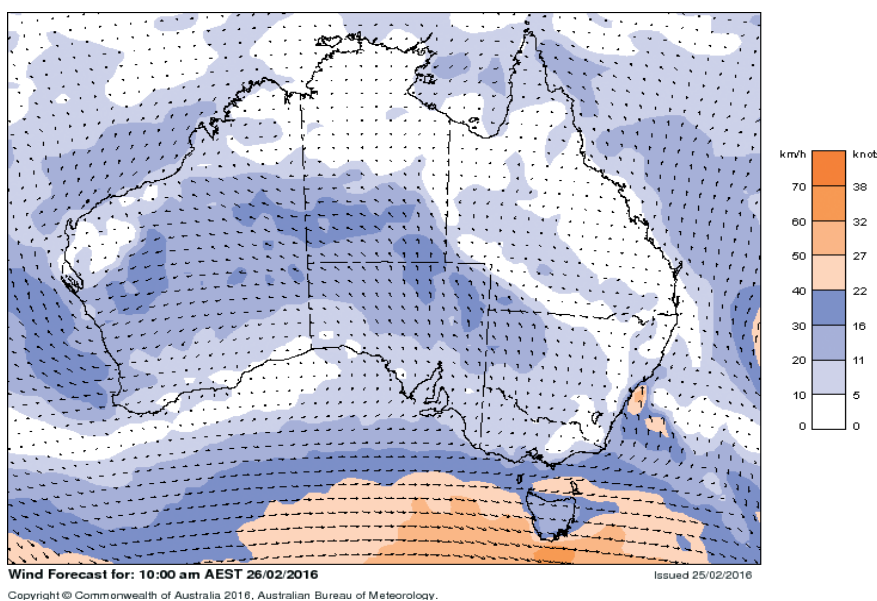


Image sourced from www.bom.gov.au

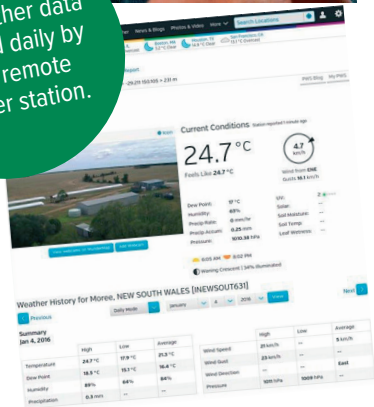
7.0 ACTIVITY

Monitoring the weather on-farm: above and below the surface

Monitoring the weather above ground provides a great insight to how the farm should be managed. But for farmers, understanding the conditions below ground is just as important. Farmers can use soil moisture probes to track not only the surrounding weather but the soil temperature, humidity and moisture throughout the soil profile. This gives farmers a sound understanding of how effective their rainfall is e.g. how far it moves down the soil profile.



The weather data received daily by Ben's remote weather station.



Ben - Farming with Innovation

Ben Boughton, a farmer from Gilroy Farms,

Moree, uses a remote weather station to keep track of daily, weekly, monthly and annual weather events.

"The remote weather station with wireless capabilities tracks the daily temperature, dew point, rainfall, pressure, UV, soil moisture, soil temperature and even leaf wetness," he says. "We have a camera mounted high on the UHF antenna to get a good overview of the farm work area."

Modern technology allows the information to be sent to a website where it can be tracked, monitored and analysed to help make important farming decisions.

"We use our remote weather station regularly for monitoring conditions for spraying such as temperature, wind and humidity," he says. "We work to minimise the potential for spray drift and we specifically want to avoid any temperature incursions."

"We also keep a close eye during August and September for below zero temperatures indicating likely frost."

About Ben's Farm:

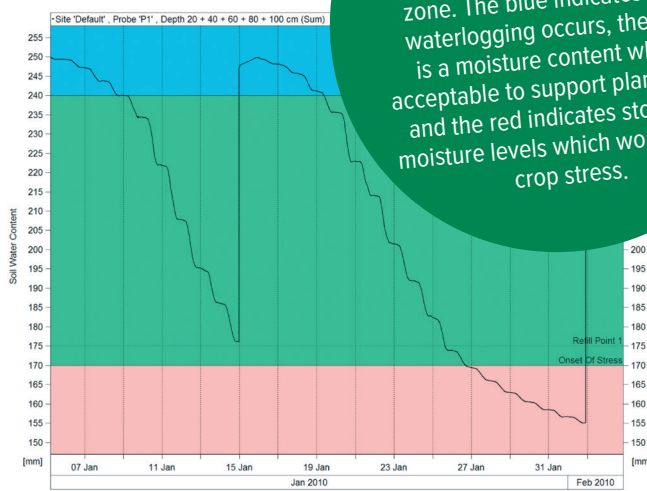
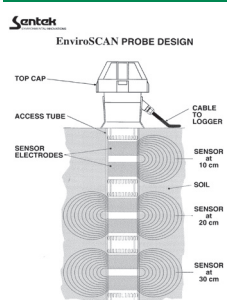
Average rainfall: 600mm

Climate: Sub-tropical

Crops grown: Winter and summer crops. Winter crops include wheat, barley and chickpeas (sometimes faba beans and canola). Summer crops include sorghum (sometimes mung beans and cotton).



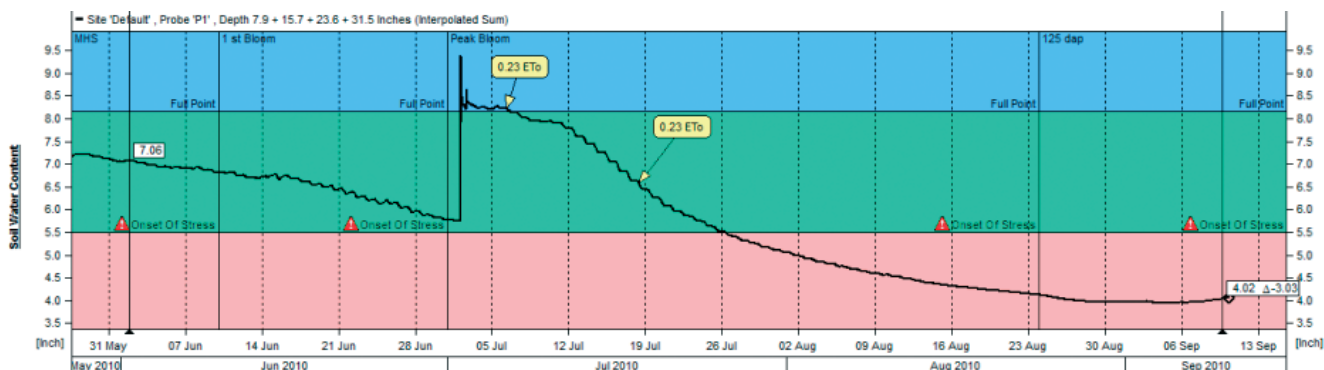
The probes have sensors which record moisture at 10, 30, 50 and 70 cm deep.



SOIL MOISTURE PROBE
The soil moisture probe records the moisture within the plant root zone. The blue indicates where waterlogging occurs, the green is a moisture content which is acceptable to support plant growth and the red indicates stored soil moisture levels which would cause crop stress.

The below data was extracted from Ben's soil moisture probe from May to September.

Review the data, then answer the below questions to provide an insight into the soil moisture on his farm.



a) What day was there a rainfall event?

b) What date did the plants enter water stress mode?

c) What date and for how long did the soil hit waterlogging, or full capacity?

d) What do the bumps from July 12 to 26 indicate?

8.0 INSIGHT

The cost of frost

Frost is one climate risk that can be very costly to growers, damaging their crops and reducing their yield potential. Frosts can be extremely devastating as they are sudden impact. One frost event can ruin entire crops and yields by causing plant floret sterility, affecting the stem development and causing tiller death.

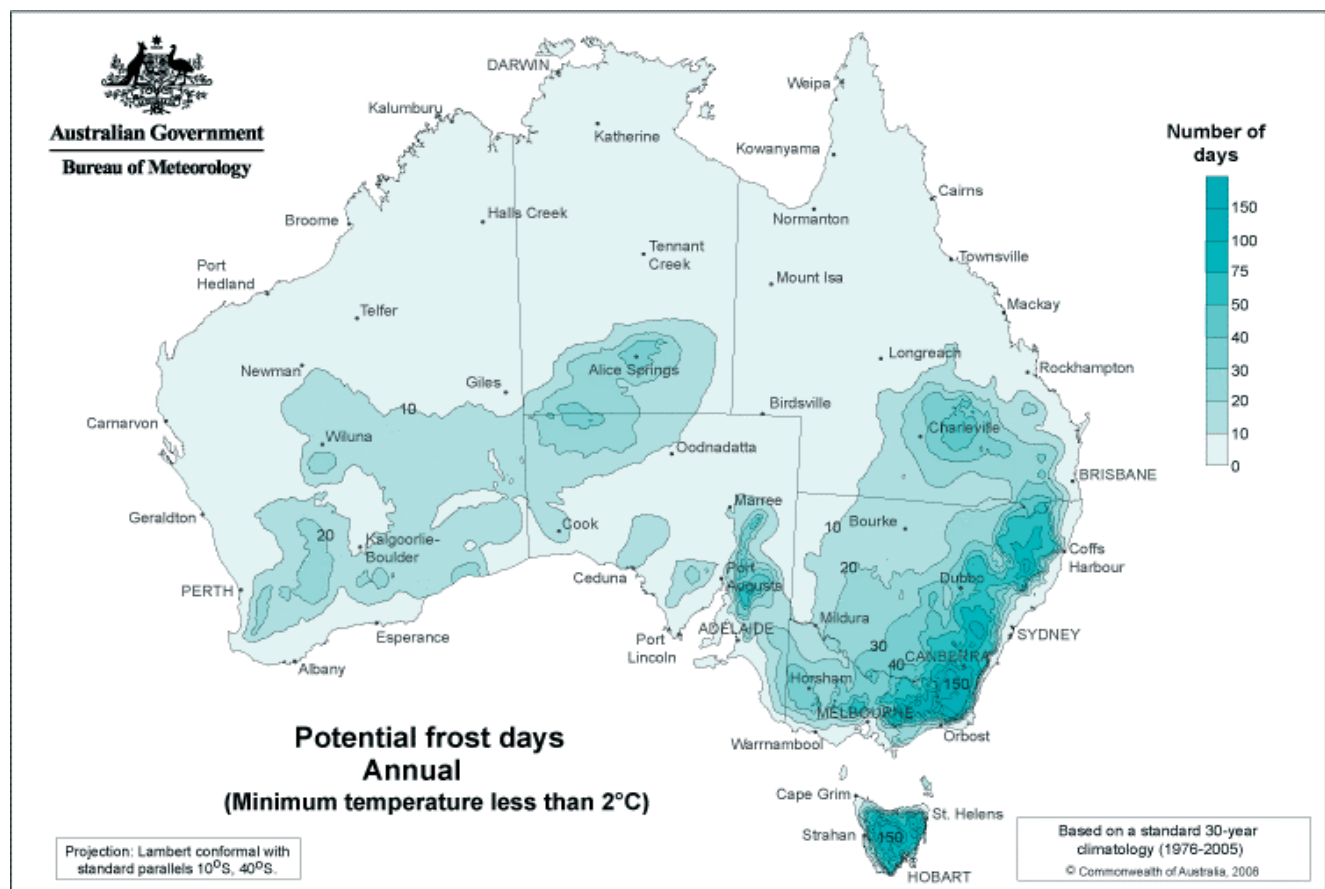
To reduce risk and ensure the best outcome for their crop, farmers need to understand historic and real-time weather data.

Emerging weather mapping and monitoring technologies help grain growers identify likely times, duration and areas within the landscape which are partial to frost events.

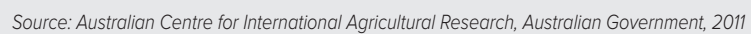
Understanding yearly trends over time can provide an understanding of when and where frost is most likely to occur in a region. Farmers can then develop a management plan considering their region's frost risks.

Activities

1. Below is a map of the potential frost days for Australia over a year, while the second map shows the area where grains and pulses are commonly grown across the country.



Source: Bureau of Meteorology, "Potential frost days", accessed October 2015



Compare the two maps and comment on what you see.

[illegible]

9.0 ACTIVITY

Frost watch!



Did you know?

Most BoM temperature measurements are taken 1.2-1.5 metres above the ground in a Stevenson Screen (Grey 2014). Frost occurs at ground level when it reaches +2.2°C in Stevenson Screen box.

The Australian Bureau of Meteorology (BOM) provides information about Australia's weather, climate and water. It provides specific data and maps to assist growers and graziers. The BOM website can be used to find information about specific regions.

TASK

Research the current frost risk in your area:

- 1) Visit **www.bom.com.au**.
- 2) On the homepage select 'Agriculture' > 'Forecast frost potential'.
- 3) Click on your state.

Summarise the current frost potential for your state.

TASK

Investigate how frost is affecting your area considering landscape, topography and time of year (month, day vs night).

- 1) Visit **www.bom.com.au**.
- 2) On the homepage select 'Climate and past weather' > 'Weather station data'.
- 3) Climate data online Data: Temperature > Daily > Minimum Temperature.
Choose Location > Choose Station > Choose previous year e.g. 2014.
Get Data > Select.
A table will be generated showing the daily minimum temperature.
- 4) > Show in table: days below 0°C, 2°C, 5°C

Which month do you believe poses the greatest risk of frost? Comment on the data.

10.0 INSIGHT

Frost through Australia – symptoms, severity and state distribution

The GRDC considers the following regions to be high frost risk areas:

- South Australia: the Eyre Peninsula, Murray-Mallee and the Mid-North.
- Victoria: the Wimmera-Mallee region.
- Western Australia: the southern wheat belt.

Brainstorm

Why are these areas more frost prone than others?



Understanding frost

According to Bureau of Meteorology (2016) a frost is defined as “a deposit of soft white ice crystals or frozen dew drops on objects near the ground; formed when the surface temperature falls below freezing point”.

There are two main ways that frost can form. The BOM defines radiation and advection frosts as follows:

- **Radiation frost:** Radiation is the most common mechanism for frost formation in Australia. Frost occurs when the ground and ambient air cools down by the loss of heat to the atmosphere. This mostly occurs under clear skies and with little or no wind. Radiation frost begins at ground level and gradually rises to higher objects.
- **Advection frost:** Advection frost (also known as “freeze”) can occur at any time, day or night. Frost forms when a mass of very cold air moves over an area, replacing the warmer air in that area. It is not affected by cloud cover. This type of frost is generally not seen in Australia, as the air masses in our region are very rarely cold enough to produce a freeze.

Reference: <http://www.bom.gov.au/climate/map/frost/what-is-frost.shtml>

Frost can also take several forms. The two most common forms of frost seen in Australia are:

- **White frost:** White frosts are the most common frosts in Australia. You will see white frosts on your car windscreens! “A white frost is a deposit of ice crystals formed by direct deposition on objects exposed to the air.” (BOM 2016) Water vapour in the air freezes upon contact with an object that has a surface temperature below 0°C (BOM 2016).
- **Black frost (or dry freeze):** “Black frost occurs when the temperature drops to freezing point, but the adjacent air does not contain enough moisture to form white frost on exposed surfaces. This causes an internal freezing of the vegetation, leaving it with a blackened appearance and killing it. Black frost is fairly uncommon in Australia.” (BOM 2016)

Frost conditions

A range of weather conditions will influence the length and severity of a frost.

Clear skies: When there is no cloud cover, heat from the earth's surface is lost. This makes the crop colder.

Humid air: When there is moisture in the air, the likelihood of frost decreases because the changes in the state of water are altered (vapour – solid – liquid).

Wind: Wind can mix up the cool air at the earth's surface and the warm air radiating off the earth's surface. This means frost is less likely.



Case study

Forecasting frosts

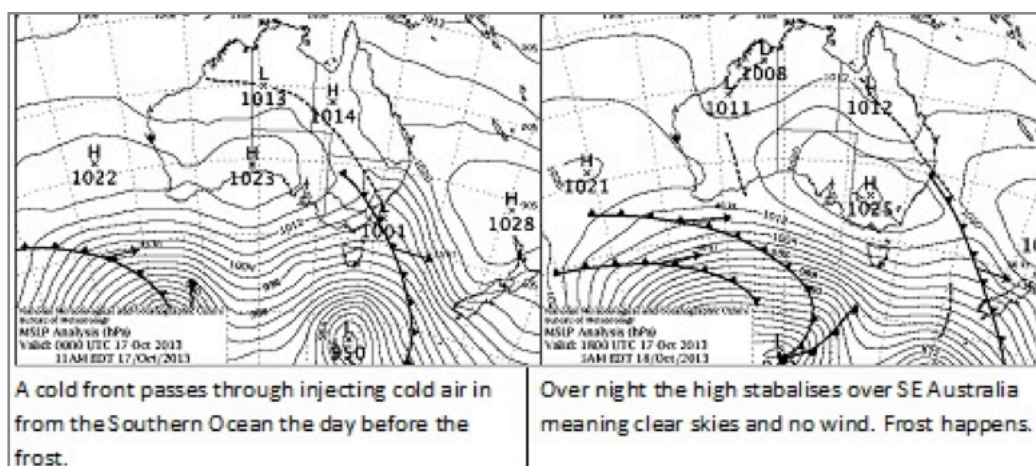
Research scientist Dale Grey states that: "Clear, calm and dry nights following cold days are the precursor conditions for a radiation frost. These conditions are most often in southern Australia during winter and spring where high pressures follow a cold front, bringing cold air and cloudless conditions from the southern ocean."

Other frost forecast facts include:

- Frosts are more likely to occur when the loss of heat from the earth during the night decreases the temperature at ground level to zero.
- Frost risk is reduced when there is wind and cloud.
- The extent of frost damage is determined by how quickly the temperature takes to get to zero, the length of time it stays below zero and how far below zero it gets.

ACTIVITY

Review the below weather system maps from 17 October 2013 and comment on the conditions which resulted in frost. Extend this research and investigate historic weather information on BOM. Search for a site then review its temperature, wind speed, dew point and humidity. Summarise the forecast for your region.



Reference: Grey, D (2014) Frost damage in crops – where to from here?
Viewed online at: <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here>

11.0 INSIGHT

Frosty conditions

Plants can get frost bite! Ouch. Here's how frost affects plants:

Chilling injury: Chilling injuries occur when temperatures are less than 10°C and down to 1°C. At these temperatures, no ice crystallisation in the leaf tissue occurs but the plant's metabolic functions can be impaired which in turn affects their pollen, ovule or embryo (Rebbeck and Knell 2007). In the worst case, the plant can become sterile which means no seed sets.

Freezing injury: Freezing injury occurs when temperatures go below -2°C. In this case, ice can form in the plant tissues which causes mechanical damage, e.g. since water expands when it turns into ice, it can result in ice splinters which pierce through cellular organelles causing significant damage or even cell death. Freezing injuries can also occur through a dehydration mechanism. In this case the available water freezing results in cellular dehydration.



Did you know?



The GRDC has a range of frost research projects on the go...

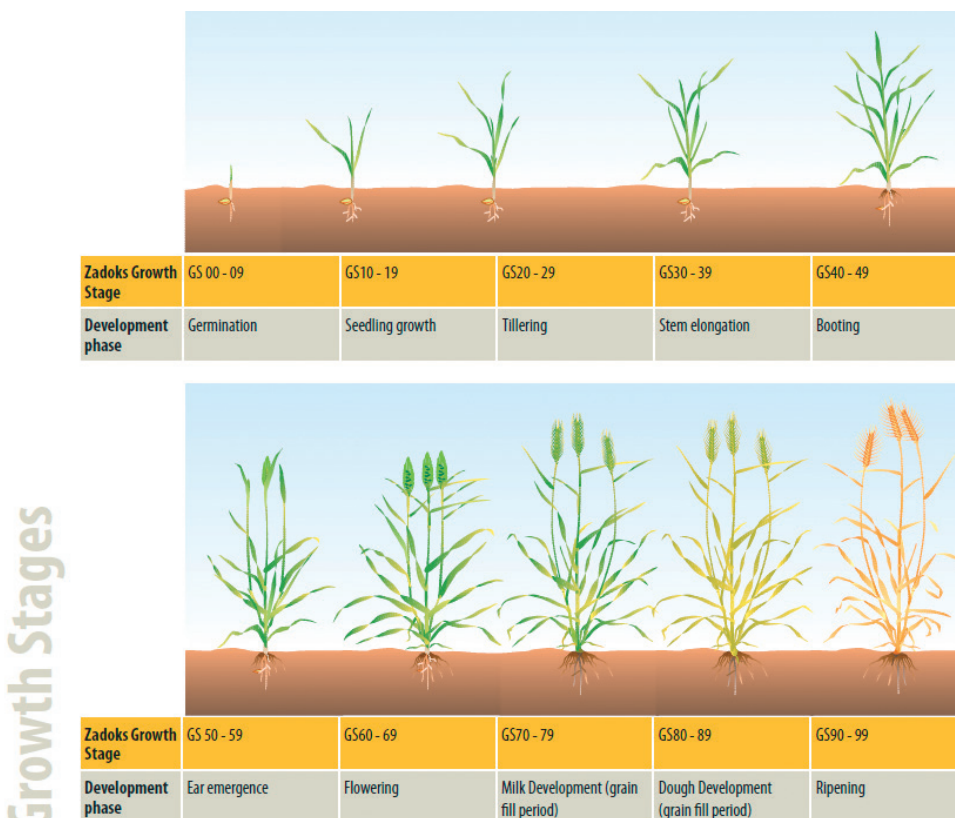
- 1) Plant breeders are searching the world for frost tolerant wheat and barley varieties.
- 2) Research scientists are developing sowing guides for farmers which detail the least frost-risk time of sowing. This will minimise a plant's frost risk by avoiding flowering in high frost periods.
- 3) Molecular biologists are working to understand the genes involved in a plant's frost response.
- 4) Agronomists are working with farmers to design improved farming systems which consider landscape variation, use of stubble and topography buffers.
- 5) Meteorologists are developing improved weather monitoring tools.
- 6) Engineers are building better on-farm weather monitoring stations.

Timing matters

The Zadok Scale is a decimal scale which defines the development of cereal crops in a number of stages. It is used by farmers, agronomists and researchers in making management decisions. Cereal crops are most susceptible to frost damage in the following stages: Ear Emergence (Growth Stage (GS) 50-59), flowering (GS 60-69) and milk development / grain fill period (GS 70-79).

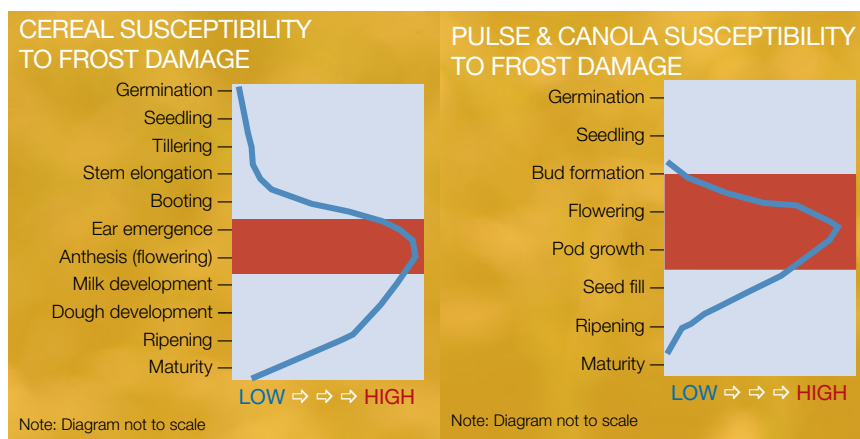
On the Zadok Scale, circle the stages of barley development which are at severe risk in the event of frost.

HINT: use the below graphs to identify susceptibility



Barley plants' development can be tracked against a special chart developed by scientists. 'Zadok's Key' provides a number from 1 to 100 to reflect a specific growth stage of the plant. For example Growth Stage 10 to 19 is when the plant is just a seedling while stage 60-69 is when the plant is flowering. This is a very handy tool to help farmers decide if and when the plant might need fertiliser or some extra care.

Zadoks cereal growth stages (image derived from the GRDC Cereal Growth Stages Guide).



Stage of high risk of frost

Cereal crops

Pulse and canola crops

Frost Risk Fact Sheet' GRDC, 2009 http://www.grdc.com.au/uploads/documents/GRDC_FS_Frost.pdf

Temperature matters

Not all frosts will affect plants. The actual temperature, combined with the length of time and the stage of plant development (plant height, flowering stage) all influence how a plant will survive the frost. The below table indicates the critical temperatures which can affect a frost.

Temperatures of 2.2°C or below are known to cause frost in flowering crops (Grey 2014). In general, an official temperature of 0°C will have a negative effect on crops of any crop height, but when temperatures are between 0 and 2°C, the effect is more variable (Grey 2014). The below tables summarise the impacts of frost on cereal crops at a range of temperatures. It also suggests what temperatures affect what part of the plant.

GROWTH STAGE	PLANT DEVELOPMENT	APPROXIMATE TEMPERATURE OF >2HRS	SYMPTOM	IMPACT
Single stem	First stem protrudes from the soil.	- 7°C	Leaves die, plant may die.	Severe
Tillering	Stems which grow off the original stem.	-11°C	Burning of leaf tips, odour.	Slight to moderate
Jointing	Nodes appear on the stem.	-4°C	Leaf yellowing or burning, lesions, splitting, bending at flower stem, death of plant.	Moderate to severe
Boot	Tightly coiled flag leaf which protects the head as it moves up the plant.	-2°C	Spike trapped in boot, damage to lower stem, leaf discolouration.	Moderate to severe
Heading	Head of the cereal plant emerges.	-1°C	White heads, damage to lower stem, leaf discolouration, plant becomes sterile.	Severe

Table 1.1 Critical temperatures (celsius) where frost can cause damage to crops

CROP	GERMINATION	FLOWERING	FRUITING
Spring wheat	-9, -10	-1, -2	-2, -4
Oats	-8, -9	-1, -2	-2, -4
Barley	-7, -8	-1, -2	-2, -4
Peas	-7, -8	-2, -3	-3, -4
Lentils	-7, -8	-2, -3	-2, -4
Lupin	-6, -8	-3, -4	-3, -4
Beans	-5, -6	-2, -3	-3, -4
Soybeans	-3, -4	-2, -3	-2, -3
Corn [maize]	-2, -3	-1, -2	-2, -3
Millet	-2, -3	-1, -2	-2, -3
Sorghum	-2, -3	-1, -2	-2, -3

Food and Agricultural Organisation of the United Nations <http://www.fao.org/docrep/008/y7223e/y7223e0a.htm>

12.0 PRACTICAL

Frosty plants: symptoms of frost during early crop growth stages

Farmers must be able to identify frost damage so they can decide what, if any, management decisions need to be made. To determine the severity of frost they must:

- Understand the frost tolerance of the plant they are growing.
- Understand the plant growth stage as certain stages are more susceptible to damage than others.
- Understand the temperature and length of frost the frost event.
- Understand the key environmental conditions relevant to a frost event.

As a general rule, after a frost event growers must monitor the plants until two weeks after the event as the type and severity of damage will be visible by then.

ACTIVITY

Investigating frost damage in frozen plants

Plants live in all types of environments throughout the world. They live in deserts, oceans, swamps, mountains and even in the freezing arctic! Plant species native to cold climates have developed strategies to survive cold temperatures. Most of Australia's cereal crops evolved in the Middle East and Europe.

Frost can be devastating for the growth of a crop, causing lower yields, poor quality grains and pulses and sometimes even causing the plant to perish. Understanding the stages of growth at which a plant is most susceptible to frost is important when planning a crop. While plant breeders are working to develop varieties which are better adapted to Australia's climate, there is still work to be done, especially with regards to the development of frost tolerant varieties.

Brief

Your task is to test the effect of temperatures on plant growth and development. You need to select a range of different plants and assess

- a) if different levels of temperature affect their development,
- b) if the length of exposure to freezing temperatures plays a significant role, and
- c) if different types of plants have different levels of tolerance to the cold.

Equipment:

- Purchase either seeds or seedlings (depending on time). Suggest peas, beans and corn.
- Potting soil (note health warnings on label and ensure correct personal protective equipment is worn).
- 20 small pots
- Water/measuring cylinder and a ruler
- A freezer
- A timer/stop watch
- Plastic bags

Method

- 1 Collect three different species of plants, for example peas, beans and corn. Or you might choose to germinate cereal grains such as wheat, barley and oats.
 - a. For seedlings: Ensure each of the seedlings are in the same size pots and are at the same developmental stage.
 - b. You can choose to label the pots using different growth stages as follows:

For cereal variety (e.g. barley): [Single stem] [Tillering] [Jointing] [Boot] [Heading]

For pulse plant variety (e.g. pea): [Seedling], [Bud formation], [Flowering], [Pod Growth], [Ripening]

Also set up a [Control] pot which represents how the plant would grow if not affected by frost conditions.
 - c. For seeds: Label your containers as follows:
 - i. There will be four corn pots: pot one label as control, pot two is freezing two hours, pot three is freezing five hours, pot four is to be labelled 'flowering two hours' and pot five is 'flowering five hours'. Use the same labelling method for the bean and pea pots.
 - d. Plant three seeds into each container. This ensures you have a control and then three different treatments, plus replications in each. Plant the seeds about 2cm below the surface, pat down gently. Water, ensuring the soil is moist but not too wet.
 - e. Grow all of the pots on the window sill in the sunlight. Record the growth information of the seeds on a daily basis in the table provided.
 - f. Water plants every second day.
 - g. Once the plants have reached the seedling phase (about 25 cm tall) treatment pots two and three are ready for their freezing exposure.
 - i. Leave your control plants on the window sill.
 - ii. Place the two and five hour pots into the freezer, making sure that you start your timer. **NOTE Place a plastic bag around the base of the pot before putting in the freezer for hygiene and soil insulation.*
 - iii. Take out the two hour treatment pots after two hours.
 - iv. Take out the five hour treatment pots after five hours.
 - h. Pot four and five are flowering treatments. These treatment pots will test the effect of frost on the plant when they are flowering. This is required as plants are particularly vulnerable to frost at this delicate growth stage.
 - i. When the plants are flowering place into the freezer, being sure to set the timer. Remove the two hour treatments after two hours and the five, after five hours.
 - ii. Record the results immediately, noting any changes in appearance. You will then need to monitor the plants' growth and performance over the next three weeks.
 - i. Keep monitoring the growth of your plants, comparing the results between treatments.
 - j. You will be recording both qualitative and quantitative data as follows:
 - i. Qualitative data: what you observe, e.g. colour, shape of plant, development, seed development following flowering (noting their size, shape and colour).
 - ii. Quantitative data: what you measure, e.g. growth of plant, how many seeds the plant produces.
 - k. You can refer to the stages and symptoms of frost chart for tips on how to make visual identification of frost damage in plants.
 - v. Record the results immediately noting any changes in appearance. You will then need to monitor the plants' growth and performance over the next seven weeks.

Practical report

Describe in detail, the plants which you have chosen to use in your investigation.

Aim:

Hypothesis: Formulate a hypothesis about what you predict may happen (e.g. If (application) happens to (subject), then (result) will happen to (measurement)).

The independent variable: The one that you will change

The dependent variable: The one that you will measure

Controlled variables: factors that you will keep the same throughout the experiment to ensure they have minimal effect on the results e.g. amount of soil in each pot.

Record results: (separate page)

Discussion: interpret data (what does your data tell you), draw conclusions.

This image shows a single sheet of white paper with horizontal blue or grey ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

Conclusion: Relate findings to your hypothesis.

[illegible]

Data sheet: Height recording plant freezing experiment

TREATMENT POTS		HEIGHT WEEK 1	HEIGHT WEEK 2	HEIGHT WEEK 3	HEIGHT WEEK 4	HEIGHT WEEK 5	HEIGHT WEEK 6	HEIGHT WEEK 7
Corn	Control							
	Freezing two hours							
	Freezing five hours							
	Flowering two hours							
	Flowering five hours							
Beans	Control							
	Freezing two hours							
	Freezing five hours							
	Flowering two hours							
	Flowering five hours							
	Control							
	Freezing two hours							
	Freezing five hours							
	Flowering two hours							
	Flowering five hours							

Data sheet: Visual assessment plant freezing experiment. Make comments on the plant’s leaf, stem and seed/fruit appearance.

TREATMENT POTS		WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7
Corn	Control							
	Freezing two hours							
	Freezing five hours							
	Flowering two hours							
	Flowering five hours							
Beans	Control							
	Freezing two hours							
	Freezing five hours							
	Flowering two hours							
	Flowering five hours							
	Control							
	Freezing two hours							
	Freezing five hours							
	Flowering two hours							
	Flowering five hours							


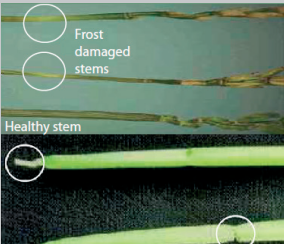


13.0 INSIGHT

What's that frost?

Stages and symptoms of frost in cereal crops

The below table summarises the crop growth stage and provides tips for how to visually assess the plant and what symptoms to look for.

Stages and symptoms of frost in cereal crops

CROP GROWTH STAGE		INSPECTION DETAILS	FROST SYMPTOMS IN WHEAT	EXAMPLE
Vegetative (before stem extension)	Examine leaves.	Leaves are limp and appear brown and scorched.		
Elongation (before and after head emergence)	Pull back leaf sheath or split stem to inspect damage.	<p>The stem has a pale green to white ring that usually appears sunken, rough to touch and soft to squeeze.</p> <p>The stem or nodes can also be cracked or blistered.</p> <p>Stems can be damaged on the peduncle (stem below head) or lower in the plant. If the head had emerged at the time of the frost then it is likely that the flowering parts or developing grain have also sustained damage. If the head is in the boot then ongoing monitoring is required to assess the level of damage.</p>		 
Flowering and post-flowering	Peel back the lemma (husk), inspect the condition of the florets (floral organs) in the head.	Flowering is the most vulnerable stage because exposed florets cannot tolerate low temperatures and are sterilised. Grain will not form in frosted florets but some surviving florets may not be affected. Pollen sacs (anthers) are normally bright yellow but become dry, banana-shaped and turn pale yellow or white when affected by frost.		

ACTIVITY

What's that frost?

Using the table 'Stages and symptoms of frost', assess each image and predict the likely severity and type of frost damage and the subsequent implications for the plant.











Brainstorm

A grower's frost management plan



In a farming area identified as frost prone, a farmer must have a pre, in season and post management plan.

- PRE:** What species or variety should I plant? Where in the landscape is most frost prone and how should I manage this?
- DURING:** Am I monitoring the temperature fluctuations so I can assess the damage? Are there fans or other technologies which might help?
- POST:** What should I do with my crop now? Should I leave it e.g. will it recover or should I cut it for hay or other?

Can you think of two ways you could help lower the risk of frost?

Weather stations on farms provide localised temperature data. However, they are not considered to be representative of risk of frost within the crop. Why do you think this is?

List factors which determine the risk of frost

14.0 ACTIVITY

Grain storm

There are several ways that the weather can be monitored. For grain growers to be able to closely monitor and manage their crops they need real-time information. The development of technology paired with access with historical records enable growers to monitor their plant selection, sowing time and crop management better.

The below graphs were generated using an online crop production model to help growers with their decision making. Each graph shows a different variety grown in the same area: 'Yitpi' and 'Young A', grown in the Culgoa area of Victoria.

Along the X axis is the trialled sowing dates, while along the left Y axis is the yield which resulted from sowing at that time. The right Y axis shows the risk of heat and frost as a percentage.

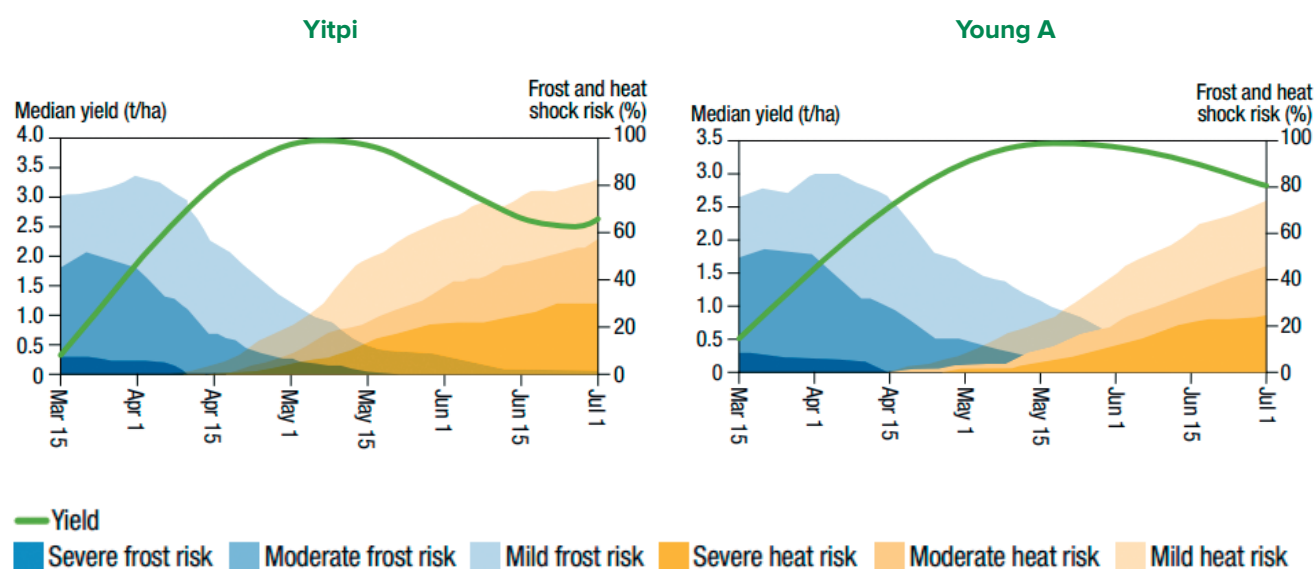


Figure 1: These graphs show the optimal sowing time of two varieties of wheat: 'Yitpi' and 'Young A'. Both were planted in a specific paddock at Culgoa in north-west Victoria

Source: Yield Prophet®

Compare the two graphs and summarise in the following table.

VARIETY	YITPI	YOUNG A
Median Yield if Sown 1st April (t/ha)		
Severe Frost Risk Susceptibility (%)		
Mild Frost Risk		
Susceptibility (%)		
Median Yield if Sown 15th May (t/ha)		
Mild Frost Risk		
Susceptibility (%)		
Moderate heat risk		
Susceptibility (%)		
Median Yield if Sown June 15th (t/ha)		
Severe heat risk		
Susceptibility (%)		
Moderate heat risk		
Susceptibility (%)		
<p>From assessing this data, what time do you think it is best to sow these crops? Discuss for each, explaining why in terms of climate risk and yield.</p>		

15.0 ACTIVITY

Case Study Frost events in Grenfell, NSW, October 2013

Frost is always a big threat to the success of growing grains and something that farmers are always looking out for. In one night the potential yield of a crop can significantly drop if effected by frost. In October 2013 Grenfell, NSW, experienced three frost events which resulted in significant crop loss with 50 – 95% of crops being damaged.

TASK

Review the article 'Late frosts cause southern concern' (Janet Paterson, Ground Cover Supplement April, 2014). <http://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS109/Late-frosts-cause-southern-concern>

1. Answer the following questions

- Explain the topography of Mr Taylors farm

- How did a shortened spring period add to the frost damage which occurred on Mr Taylors farm?

- In the October 2013 period, what was the lowest temperature recorded at canopy level on the farm?

- What growth stage was the crop at when it was affected by frost events in October 2013?

- What do you understand about growth stages and the effect of frost?

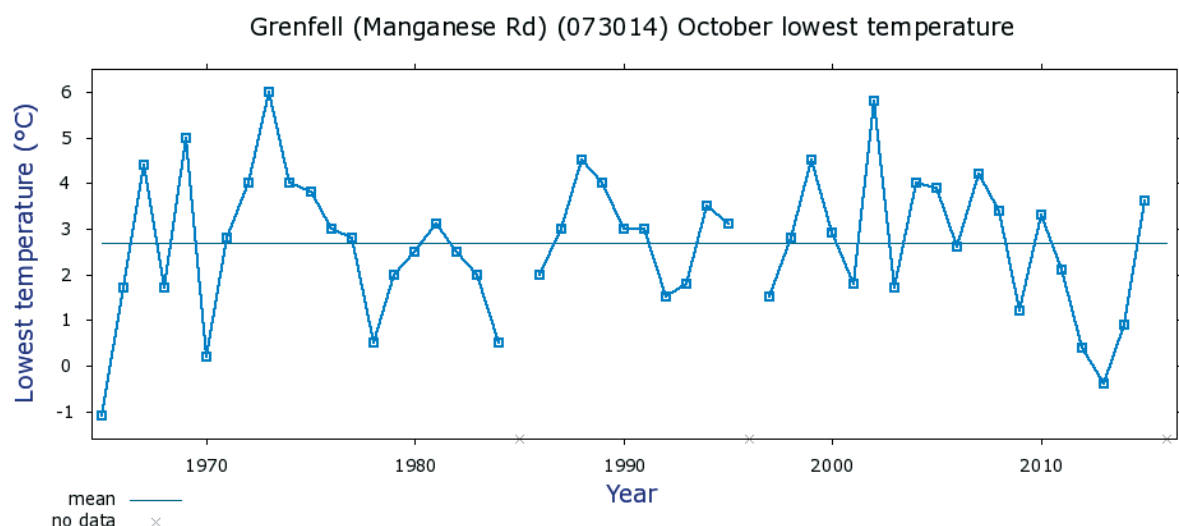
- How has the farm layout been planned to minimise risk of frost damage?

- Name two things that Mr Taylor hopes for as a result of GRDC frost research?

Table: Atmospheric Conditions Leading to a Frost Event

MEASUREMENT	3pm – 4pm	6pm – 9pm	FROST
Temperature at Screen Height <i>Screen Height: Approximately 1.2 Metres – about the height of a grain crop nearing maturity</i>	16°C → 8°C	12°C → 6°C	< 2°C
Cloud Cover	Very low	Low	Nil
Wind Speed	<3 m/s	<1 m/s	0 m/s
Barometric Pressure	1008 - 1009	1008 – 1009	1004 – 1008

2. The graph below provides a general overview of lowest recorded temperatures each year since records began in that area (1965). Highlight years which have a potential risk of frost by noting the lowest recorded temperatures.



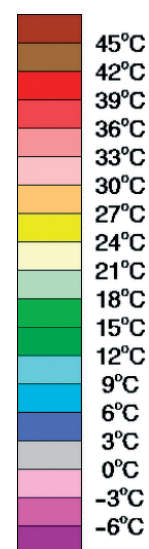
Note: Data may not have completed quality control
 Observations made before 1910 may have used non-standard equipment
 Product Code: IDCJAC0008

Climate Data Online, Bureau of Meteorology
 Copyright Commonwealth of Australia, 2016

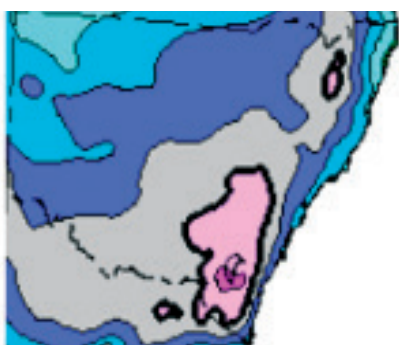
Page created: Tue 01 Mar 2016 16:23:26 PM EST

Source: BOM Historical Data, Grenfell NSW

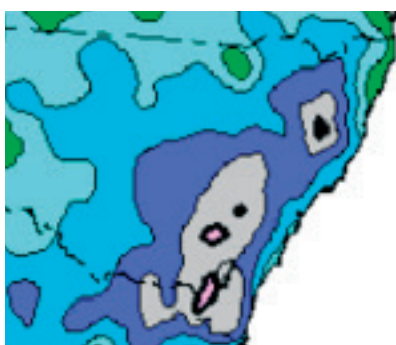
3. These maps provide an overview of the daily minimum temperature across the NSW from October 15th – 18th. Using the key, identify and record the frost risk for each day in the approximate area of Grenfell, NSW.



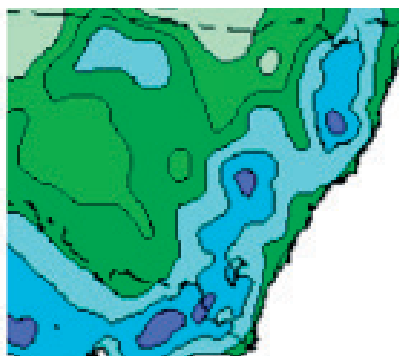
Oct 15th 2013



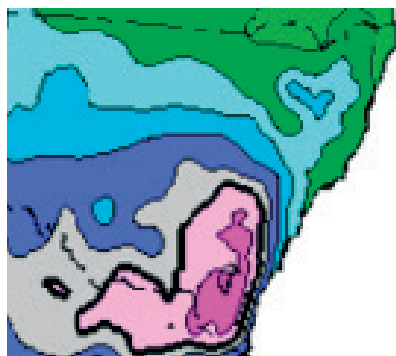
Oct 16th 2013



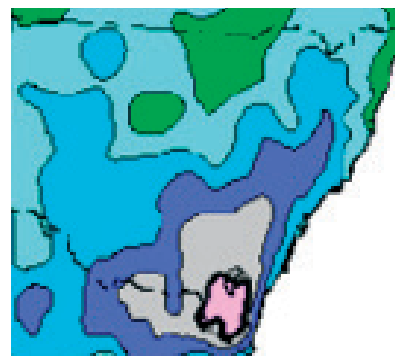
Oct 17th 2013



Oct 18th 2013



Oct 19th 2013



Source: BOM Monthly Weather Review, Oct 2013

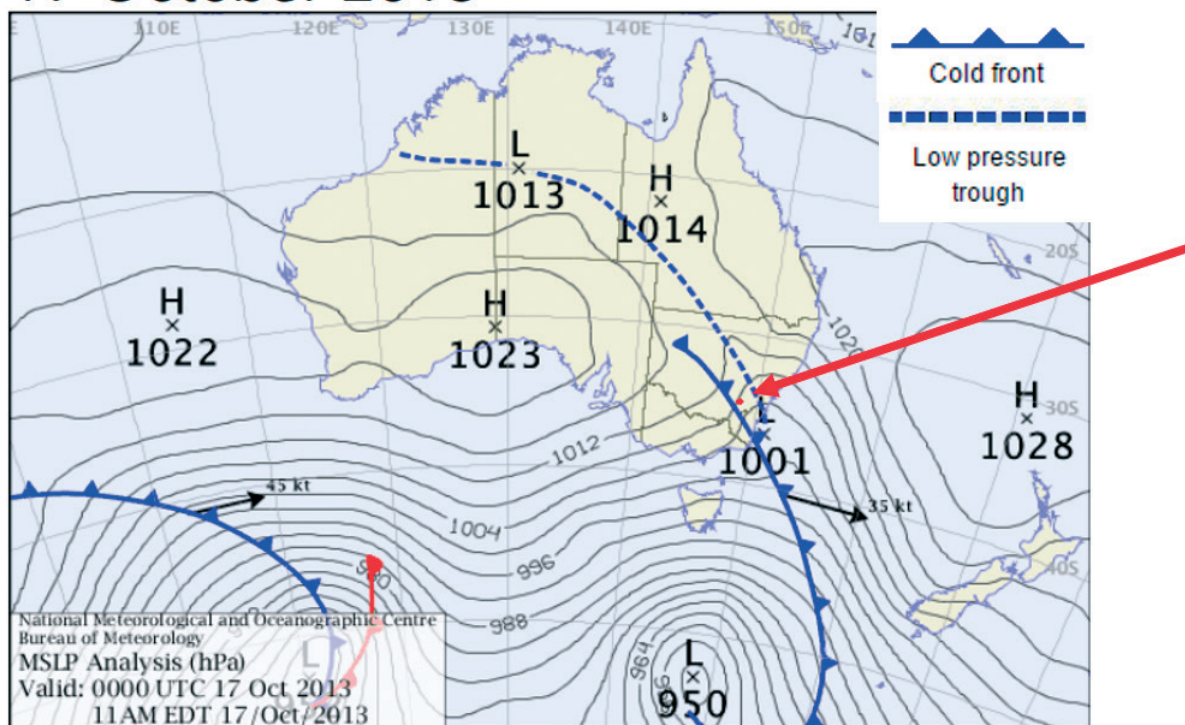
4. Below is a map showing the barometric pressure/atmospheric pressure across Australia on October 17th 2013. The lines across the map represent barometric pressure. The approximate location of Grenfell is marked by a red dot.

What is barometric pressure?

What is the barometric pressure reading for Grenfell on this day?

Compare this to the Table 'Atmospheric Conditions Leading to a Frost Event' and comment of the risk of frost.

17 October 2013



Source: BOM Monthly Weather Review, Oct 2013

16.0 PRACTICAL

Technology for Frost



Frosts are a major issue for many Australian farmers. Frost damage results in less grain produced (less yield) and poorer quality of grain. Knowing that there is likely to be conditions which increase the threat of frost allow grain farmers to implement preventative measures.

Adopting new technologies is imperative to the success of grain farming in Australia. Farmers need to monitor the temperature of their cropping environment and innovative technologies make this efficient, accurate and can provide real-time data for farmers.

TASK

Your task is to create a temperature sensor that can be used to monitor the crop environment. It must be able to record the temperature over a 24 hour period and record the data. You must then plot the data on a line graph and provide a summary of your findings.

Refer to the instruction 'In-Field Temperature Logger' to complete this.

**Alternatively, a portable weather station/digital temperature sensor could be use*



REPORT

Once you have downloaded your data from your In-field Temperature Logger, you will need to analyse your findings. Include the following

1. Location of analysis: Where did you set up your in-field logger?
2. Controls: What measures did you put in place to ensure the sensor took fair readings?
3. Effectiveness of logger: Did you have any issues in constructing or using the logger?
4. Summary of data: What does your data tell you about the temperature at crop height overnight?
5. Risk of frost: Would the temperature drop be likely to induce frost?
6. Managing frost: What ways could you manage the risk of frost?

EXTENSION

- Add a humidity sensor to your in-field logger and analyse both temperature and humidity as a measure of risk of frost
- Include an alarm or flashing light to your in-field logger when the temperature is in the optimum zone for the development of frost.



In-field Temperature Logger

CREATE

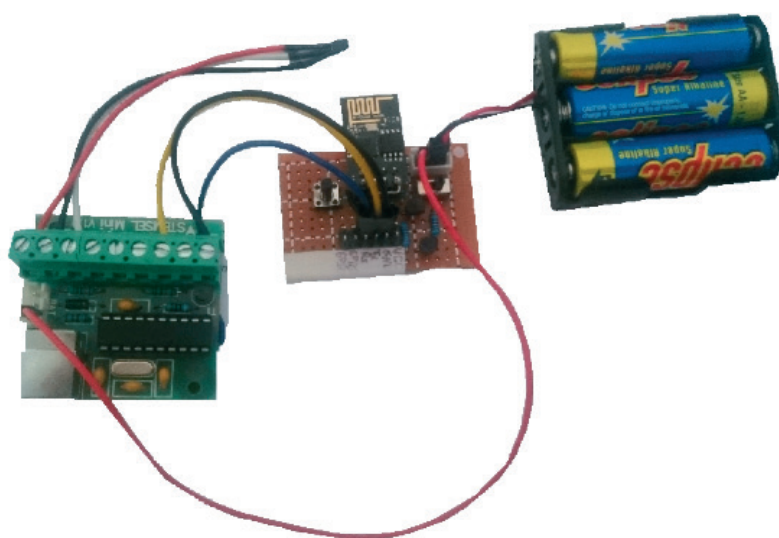
Using your preferred programming kit, create a temperature sensor which can be used out in the paddock, school garden or veggie patch to provide localised data about the potential for frost in your area. The system should be able to record temperatures at regular intervals over a large period of time (e.g. overnight). From the data generated, you will be able gain a better understanding of the temperature of an environment within a crop.

TASK:

You are a grains farmer investigating ways to monitor and manage the environment of your crop. You want to adopt technology that will help you log the air and soil temperature over a 24 hour period. To fully understand this technology, you will build this sensor yourself and then analyse the data to report of the risk of frost.

Equipment

- 1 x Waterproof enclosure (e.g. Tupperware container)
- 1 x Programmable microchip board/micro-controller e.g. STEMSEL Mini
- 1 x Waterproof DS18B20 digital temperature sensor
- 1 x USB data logging cable
- 5 x Zipties
- 1 x pole to keep unit off ground



Microcontroller/ microchip board (Graphic: STEMSEL 2015)

Programming

Follow the instructions on your programming kit to set the 'START', 'STOP' and 'INTERVAL' times.

- Enter when the logger will begin and end. The start button is used to begin taking temperature measurements. The stop button is used to terminate the current temperature measurements.
- Program the intervals at which the temperature measurements will be taken. The interval button is used to select the period between temperature readings.

START (hours)		STOP (hours)	
INTERVALS (min)			

Instructions (Using STEMSEL Mini Board)

The red wire from the battery pack connects to the centre pin of the battery connector port on the Wi-Fi circuit board.

The black wire from the battery pack can be connected to one of the pins either side of the positive wire.

A red wire is used to supply the STEMSEL Mini with power from the Wi-Fi circuit board. This connects to the middle pin of the battery connector port on the STEMSEL Mini and the furthest left pin on the Wi-Fi circuit board. Note that both rows of the far most left pins are connected to each other so either one will work. This is the same for the other pins on the connector, where both top and bottom pins are the same.

The negative wire from the Wi-Fi circuit board connects to the second from the left pin can plug into any port on the STEMSEL Mini labelled with a “negative” symbol.

The yellow wire is one of two communication lines. On the Wi-Fi circuit board it connects to the 3rd most left pin and goes to B5 on the STEMSEL Mini.

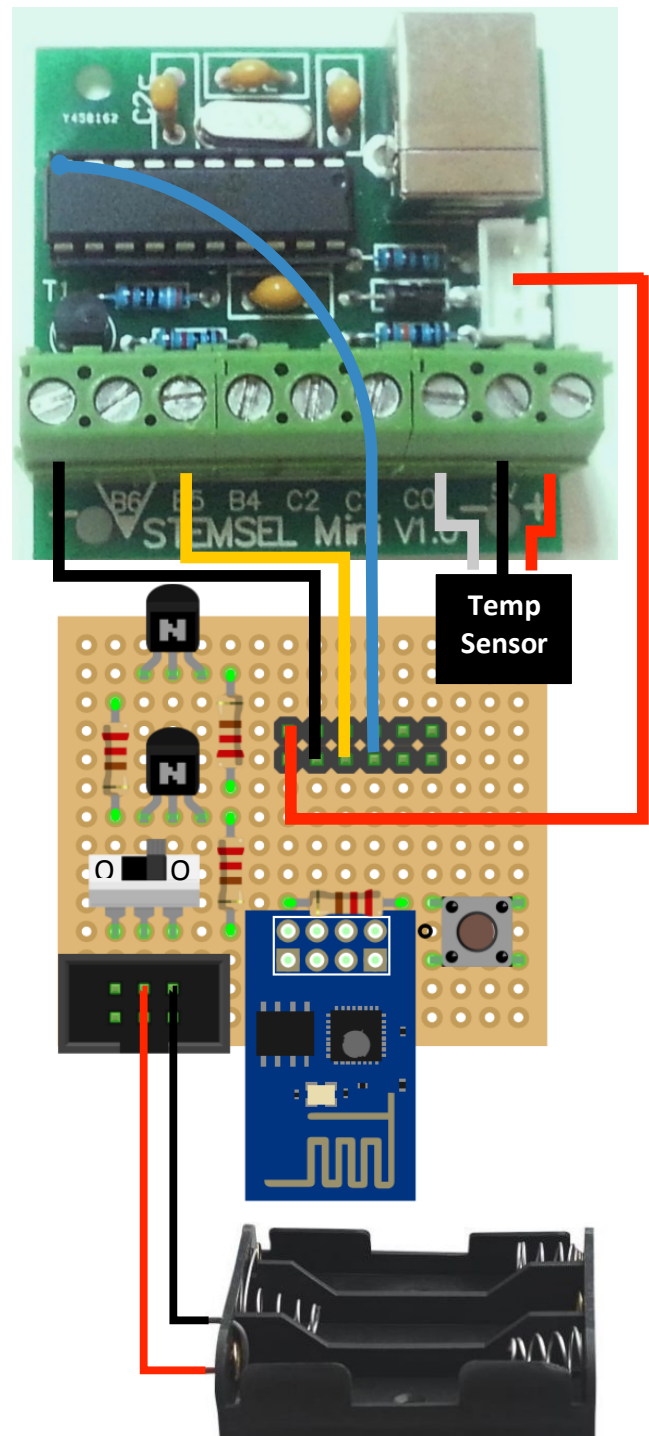
The blue wire is the other communication line which connects next to the yellow wire on the Wi-Fi circuit board.

The other end connects to the underside of the STEMSEL Mini where it is attached to the bottom left pin of the microcontroller chip.

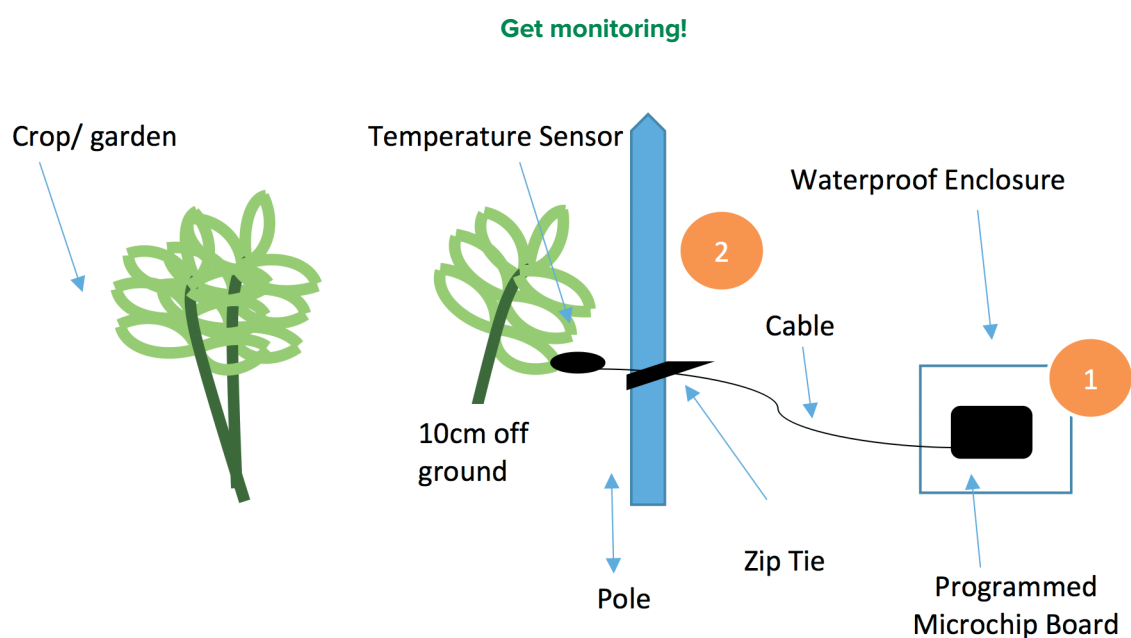
The temperature sensor has three pins. The black wire is connected to negative, the red wire is connected to positive and the white wire is connected to the C0 screw terminal.

Courtesy of Miro Kostecki, STEMSEL Foundation www.stemsel.com

Field Set up



- 1 The microcontroller/microchip board will need to be protected from the surrounding environment, particularly water. Use a sealed container and create a small hole to feed the cable out of. E.g. Tupperware container or lunchbox (ensure it is not metal if you are using a Wifi chip to record the data).
*Cable and temperature sensors are designed to be water-proof
- 2 Attach the cable to the microcontroller and then to the temperature sensor. Then attach the temperature sensor to a pole in the middle of your vegetation at the height of where the leaves grow.



Temperature Logger	
Start	Stop
Interval	Download
09:00	18°
09:30	18°
10:00	19°
10:30	20°
11:00	22°
11:30	23°
12:00	25°
12:30	26°
13:00	28°
13:30	28°
14:00	30°
14:30	32°
15:00	32°
15:30	31°
16:00	29°

How your data should appear when downloaded (Graphic: STEMSEL 2015)
<http://stemsel.com/>

Data

Following in-field monitoring, the data from the microchip/ microcontroller will need to be downloaded onto your computer for analysis using USB cable and microcontroller software. Alternatively, installation of a Wi-Fi microchip would allow data to be sent straight to a smart device.

Use this data to create a spreadsheet and graphical representation of the environment within your sample area.

Create a report on your findings. Include a table and a graph of your findings.

17.0 Good Reads

Grains Research and Development Corporation 'Plant Frost Mechanism with Glenn McDonald', 2015,
<https://www.youtube.com/watch?v=okKHYsV92FI>

Grains Research and Development Corporation, 'Ground Cover Issue 109 - Frost', April 2014, Accessed September 2015,
<http://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS109>

Grains Research and Development Corporation, 'Identifying Frost in Wheat', Accessed September 2015,
<http://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS109/Identifying-frost-in-wheat>

Many thanks to the STEMSEL Foundation for their assistance with the Frost Monitor practical, Miro Kostecki
e) miro@elabtronics.com
<http://foundation.stemsel.com/>

18.0 References

- ABC 'How do high and low pressure systems work?' Professor Steven Siems, 2013, Accessed October 2015, <http://www.abc.net.au/science/articles/2013/01/31/3679358.htm>
- ABS Year Book (2012) Geography and Climate. Viewed online at: <http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/1301.0~2012~Main%20Features~Australia's%20climate~143>
- ABARES, 'Wheat-sheep belt', Accessed October 2015, <http://www.agriculture.gov.au/abares>
- Agriculture Victoria, 'Effect of Frost on Cereal Grain Crops', 2013, Accessed September 2015, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/effect-of-frost-on-cereal-grain-crops>
- Bureau of Meteorology, 'Long-term temperature record', <http://www.bom.gov.au/climate/change/acorn-sat/>
- Bureau of Meteorology, 'Monthly Weather Review: Oct 2013', <http://www.bom.gov.au/climate/mwr/aus/mwr-aus-201310.pdf>
- Bureau of Meteorology, 'Potential Frost Days', Accessed October 2015, www.bom.gov.au
- Bureau of Meteorology, 'Indigenous Seasonal Descriptors', 2014, Accessed October 2015, http://www.bom.gov.au/iwk/climate_culture/Indig_seasons.shtml
- Grains Research and Development Corporation 'Frost Risk Fact Sheet', March 2009, Accessed September 2015, http://www.grdc.com.au/uploads/documents/GRDC_FS_Frost.pdf
<http://www.nvtonline.com.au/wp-content/uploads/2013/02/Zadoks-Growth-Scale.pdf>
- Food and Agricultural Organisation of the United Nations, 'Frost Damage: Physiology and Critical Temperatures', Accessed October 2015, <http://www.fao.org/docrep/008/y7223e/y7223e0a.htm>
- GRDC, 'Time of Sowing – Southern Region', 2011, file:///C:/Users/Downloads/GRDCFSTimeOfSowingsouthpdf.pdf
- PULSEAUS, 'Minimising Frost Damage in Pulses', 2015, Accessed December 2015, www.pulseaus.com.au
- Rebbeck, M and Knell, G (2007) Managing Frost Risk A Guide for Southern Australian Grains. Viewed online at: file:///C:/Users/User/Downloads/Managing%20Frost%20Risk.pdf