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GRDC GROWNOTES™

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

CHICKPEA

SECTION 14

ENVIRONMENTAL ISSUES

FROST ISSUES FOR CHICKPEAS | TEMPERATURE | WATERLOGGING/FLOODING ISSUES FOR CHICKPEAS | DROUGHT STRESS

Environmental issues

Key messages

- Environmental stresses during seed development have a negative effect on the quality of chickpea seeds.
- Freezing temperatures at the late vegetative stage in chickpea development can cause considerable damage and yield losses.
- Chickpea is prone to waterlogging, and as there are no in-crop control measures to deal with waterlogging, a critical management tool is avoidance of high-risk paddocks (based on previous experience and paddock history). [1]
- Both low and high temperatures can limit the growth and grain yield of chickpea at all phenological stages. Temperature is a major environmental factor regulating the timing of flowering thus influencing grain yield.
- After disease, the major constraint to greater chickpea production is its sensitivity to the end-of-season drought that occurs in both the Mediterranean-type climates and when grown on stored soil moisture in the summer- rainfall region of Australia. Unlike many other crops, chickpea is unable to escape this terminal drought through rapid development because low temperatures (less than 15°C) often cause flower and pod abortion.
- Chickpea is sensitive to salinity, and can have difficulty accessing water and nutrients from saline layers in the soil.
- Chickpea is classified among the most sensitive of all field crops to sodic soil conditions.

14.1 Frost issues for chickpeas

Radiant can be frost is a major stress to crops, and one of the principal limiting factors for agricultural production worldwide, including Australia. Radiant frosts occur when plants and soil absorb sunlight during the day and radiate heat during the night when the sky is clear and the air is still. Dense, chilled air settles into the lowest areas of the canopy, where the most serious frost damage occurs. The cold air causes the plasma membrane in plant tissues to rupture. [2]

The historical incidence of frost greatly varies across the agricultural regions of WA, with greatest occurrence in the central, eastern and southern regions. Northern and coastal regions in general have a lower risk.

In 2016 parts of WA felt the effect of very damaging frost, with some growers around Kondinin facing crop losses of up to ~70%. [3]

Legumes, including chickpeas, field peas, faba beans and lentils, are very sensitive to chilling and freezing temperatures, particularly at the stages of flowering, early pod formation and seed filling, although damage may occur at any stage of development.

Frosts (or isolated freezing events) are a problem for chickpeas (Figure 1) in south-western Australia, especially when they occur in the late vegetative and reproductive phenological (climate-induced developmental) stages, and the air temperature drops to 2°C or less on clear nights in early spring. They occur most frequently after the

1 W Parker. Desi Chickpea Essentials. DAFWA, https://www.agric.wa.gov.au/chickpeas/desi-chickpea-essentials

2 A Maqbool, S Shafiq, L Lake (2010) Radiant frost tolerance in pulse crops: a review. Euphytica 172 (1), 1–12.

3 B Varischetti. (2016). Frost wipes out 70 per cent of WA farmer's wheat crop. ABC Rural. http://www.abc.net.au/news/2016-10-05/frost-devastation-in-kondinin/7906428

passing of a cold front, when the moisture and wind dissipates, leaving cold and still conditions with clear skies.

Figure 1: *Frost damage to a chickpea crop.*

Source: ABC Rural 2013

The occurrence and extent of frost damage tends to be affected by the microclimate, with great variability occurring within paddocks and even on the same plant. Frost conditions can be amplified by climatic conditions such as clear sky, dry atmosphere, and windless conditions.

Soil type, soil moisture, position in the landscape, and crop density can also have a bearing on the damage caused by a frost event. In some species, crop nutrition has been shown to mitigate the effect of freezing range temperatures on the plant. It is thought that fertilisation of the plant, and consequent fast growth rates, can exacerbate the effect of freezing, particularly on the part of the plant undergoing elongation. [4]

WATCH: GCTV20: Extreme temperature analysis to better understand Frost events.

MORE INFORMATION

The science of frost

4 A Maqbool, S Shafiq, L Lake (2010) Radiant frost tolerance in pulse crops—a review. Euphytica, 172(1), 1–12.

14.1.1 Impacts on chickpea

Chickpeas are rated as one of the least tolerant pulses to frost events (Table 1).

Table 1: *Order of frost tolerance in pulses.*

Crop in order of tolerance (highest to lowest)	Notes
Faba beans	Faba beans have a medium tolerance to frost due to thick pod walls, which provide insulation to the developing seed.
Lupins	Lupins have a low frost tolerance and are generally unable to compensate after flowering.
Field peas	Field peas have a low tolerance due to thin pods walls and exposure of the pods to the atmosphere.
Chickpeas	Chickpeas have a low tolerance to frost due to the exposed nature of the flowers.

Source: DAFWA

Though chickpea seedlings are tolerant of frost, the plants have low tolerance to frost during the flowering stage due to the exposed nature of flowers.

Isolated frost events during the reproductive stage commonly result in flower or pod abortion, and this can be detrimental to yield in environments that experience terminal drought.

During frost events, the temperature decreases to levels cold enough to cause nucleation of the intracellular fluid and the subsequent rupturing of the plasma membrane. Damage can also be caused via dehydration of cells as a result of the freezing of the extracellular spaces. [5]

Symptoms of frost in chickpeas:

- Leaf margins are bleached.
- Flowers are killed.
- Growing points are sometimes distorted (bent) during early vegetative and flowering stages.
- Pods may develop, but seeds abort.
- Even after a frost, chickpeas will continue to flower and set pods well into spring. [6]

Damage to vegetative growth

Damage is more likely to occur where the crop has grown rapidly during a period of warm weather, and is then subjected to freezing temperatures. In chickpea, the elongation regions are often the first affected by freezing, and this can show up in a frost-damaged plant by sigmoidal curves around the elongation point—commonly referred to as 'hockey stick' symptom. Depending on the minimum temperature and the duration of the frost, plants may be partially damaged or killed, resulting in lower yield and quality at harvest or even complete crop failure.

Sub-zero temperatures in winter and spring can damage leaves and stems of the plant. Frosts can cause bleaching of leaves, especially on the margins, and a 'hockey-stick' bend (Figure 2). However, chickpea has an excellent ability to recover from this superficial damage and is able to regenerate new branches in severe cases. Late frosts also cause flower, pod and seed abortion.

5 A Maqbool, S Shafiq, L Lake (2010) Radiant frost tolerance in pulse crops—a review. Euphytica, 172(1), 1–12.

6 B Biddulph. (2016). Frost: diagnosing the problem. DAFWA. https://www.agric.wa.gov.au/frost/frost-diagnosing-problem?page=0%2C1

Figure 2: *Frost can cause bends like a hockey stick in chickpea stems.*

Photo S Loss. Source: DAFWA

Visible effect may occur as patches in the field, or on individual plants or branches of plants. Damage is usually more severe where stubble has been retained. Regrowth will generally occur provided soil moisture levels are adequate.

Chickpea may be able to recover to flower and set pods following an isolated frost event during the reproductive growth stage, provided soil moisture conditions are favourable during the subsequent periods.

In the field, frost tolerance decreases from the vegetative stage to reproductive stage. [7]

Damage to flowers and pods

Freezing temperatures damage leaves and destroy flowers and young developing seed (Figures 3 and 4). The time and duration of flowering affects tolerance and the ability to compensate after the frost has occurred. Early flowers are often aborted in chickpea, but if soil moisture is available long-duration cultivars compensate for the loss. Frosts that occur toward the end of the reproductive period following pod-set are more damaging, resulting in the abortion of pods and large yield reduction. [8]

Frost will normally affect the earliest formed pods low on the primary and secondary branches. By contrast, pod abortion induced by moisture stress is normally noted on the last-formed pods at the tips of the branches. Pods at a later stage of development are generally more resistant to frost than flowers and small pods, but may suffer some mottled darkening of the seed coat. Varieties with an extended podding period can compensate for damage better than varieties that tend to pod up over a shorter period provided soil moisture levels are adequate.

Minimum temperatures below 5°C during the reproductive stage will kill the crop, but new regrowth can occur from the base of the killed plants if moisture conditions are favourable. [9]

Frost is most damaging to yield:

- when it occurs during later flowering–early pod fill; and

7 A Maqbool, S Shafiq, L Lake (2010) Radiant frost tolerance in pulse crops—a review. Euphytica, 172(1), 1–12.

8 JS Croser, HJ Clarke, KHM Siddique, TN Khan (2003) Low-temperature stress: implications for chickpea (Cicer arietinum L.) improvement. Critical Reviews in Plant Sciences, 22(2), 185–219.

9 Pulse Australia Ltd (2013) Northern chickpea best management practices training course manual—2013.

- under dry conditions where moisture limits the plant's ability to re-flower and compensate for frost damage.

Figure 3: *Frost damage to leaves.*

Photo: G: Cumming, Source: Pulse Australia

Figure 4: *Frosted chickpea at flowering.*

Source: Pulse Australia

MORE INFORMATION

[Pulse and canola – Frost identification, Back pocket guide.]

14.1.2 Industry costs

The real cost of frost is a combination of the actual cost due to both reduced yield and quality, along with the hidden cost of management tactics used to try and minimise frost risk. The hidden costs associated with conservative management to minimise frost risk includes:

- delayed sowing and its associated yield reduction;
- sowing less profitable crops such as barley and oats; and
- avoiding cropping on the valley floors, which also contain some of the most productive parts of the landscape.

WATCH: GCTV20: Frost's emotional impact, is it greater than its economic impact?

14.1.3 Managing to lower frost risk

The different conditions under which the frost occurs will influence what management practices will be more effective. Management practices include:

- Delay flowering.
- Avoid high inputs.
- Sow more frost tolerant crops and pastures.
- Grow hay.
- Avoid sowing susceptible crops in frost prone areas, such as low-lying areas.
- Sow and graze dual-purpose crops.
- Encourage cold air drainage. Consult a specialist.
- Clay sandy-surfaced paddocks.

Frost risk is difficult to manage in pulses, however some management strategies may reduce the risk or the extent of damage. These include:

- Knowing the topography, and map areas of greatest risk so that they can be managed to minimise frost damage.
- Choosing the right crop type, crop variety and sowing time to reduce exposure or impact at vulnerable growth stages.
- Carefully assessing the soil type, condition, and soil-moisture levels, and managing stubble and the crop canopy.
- Correcting crop nutrition and minimising stressors of the crop to influence the degree of frost damage.

Ensure crops have an adequate supply of trace elements and macronutrients. Crops deficient or marginal in potassium and copper are likely to be more susceptible to frost damage, and this may also be the case for molybdenum. [10]

Problem areas and timings

Mapping or marking areas identified as frost-prone will enable growers to target frost and crop management strategies to these high-risk areas.

Knowing when the period of greatest probability of frost occurs is also important for crop management.

10 Pulse Australia (2015) Minimising frost damage in pulses. Australian Pulse Bulletin. Updated 20 November, http://pulseaus.com.au/growing-pulses/publications/minimise-frost-damage

Crop and sowing time

The main strategy used to minimise frost risk in broadacre cropping has been to sow crops later. Risks exist with delayed sowing, even though this practice can reduce the probability of crops flowering in a frost-risk period. Crops sown later can still be affected by frost.

Strategies to minimise frost damage in pulses work in combinations of:

- growing a more tolerant species
- trying to avoid having peak flowering and early podding during the period of most risk
- extended flowering to compensate for losses to frost
- ensuring that most grain is sufficiently filled to avoid damage when frost occurs (Table 1).

Targeting flowering and early podding to periods of the lowest probability of frost is achieved through combinations of sowing date and variety choice based on flowering time and flowering duration. Local experience will indicate the best choices.

By planting for late flowering, farmers target the avoidance of early frosts, but in the absence of frost, late flowering may reduce yields if moisture is deficient or there are high temperatures.

Very early flowering can allow pods to be sufficiently developed to escape frost damage, and ensure some grain yield at least before a frost occurs. Increased disease risk needs to be considered with early sowing.

Spread the risk

Match different pulses to risk areas by sowing a different variety or species into targeted areas within the same paddock. Matching the crop, variety, sowing date and subsequent inputs to the frost-risk location spreads the risk.

Have forage as an optional use. Designating hay or forage as a possible use for the pulse in paddocks with a high frost risk provides flexibility.

Mixing two pulse varieties (e.g. long and short season, tall and short) balances the risks of frost and of end-of-season (terminal) drought, and reduces the risk of losses from any one-frost event. Multiple frost events can damage both varieties. If grain from both varieties is not of the same delivery grade, then only the lowest grade is achieved. The only realistic, practical options are in peas, narrow-leafed lupins, kabuli chickpeas; perhaps desi chickpeas are an option. Differences in flowering times are minimal in lentils and beans.

Sowing a mixture of pulse species is feasible, but not common. Complications in crop choice include achieving contrasting grain sizes, herbicide requirements, harvest timing and grain cleaning. Multiple frosts may damage both crops. Pulses grown in a mix will be suitable for feed markets only unless they can be cleaned to enable purity in segregation. If these difficulties can be overcome there is an opportunity for alternate-row sowing of different pulses.

Reduce frost damage

Managing inputs

To minimise financial risk in frost-prone paddocks when growing susceptible crops, growers can:

- Apply conservative rates of fertilisers to frost-prone parts of the landscape.
- Avoid using high sowing rates.

Advantages of avoiding high inputs are:

- Less financial loss if the crop is badly frosted.

- Lower-input crops, though potentially lower yielding during favourable seasons, are less like to suffer severe frost damage than higher-input crops with a denser canopy.
- Input costs saved on the higher frost-risk paddocks may be invested in other areas where frost risk is lower.

Lower sowing rates may result in a less dense canopy and may allow more heating of the ground during the day, and transfer of this heat to the canopy at night. However, there is no hard evidence that lower sowing rates will reduce frost damage.

The main disadvantage of this practice is that in the absence of frost, lower grain yield and/or protein may be the result during favourable seasons, contributing to the hidden cost of frost. (This is a particular disadvantage in barley and wheat delivery grades.) Less-vigorous crops can also result in the crop being less competitive with weeds.

Managing nodulation and nutrition.

Ensure pulse crops are adequately nodulated and fixing nitrogen. Ensure pulses have an adequate supply of trace elements and macronutrients, although supplying high levels is unlikely to increase frost tolerance. Crops deficient or marginal in potassium and copper are likely to be more susceptible to frost damage, and this may also be the case for molybdenum. Foliar application of copper, zinc or manganese may assist, but only if the crop is deficient in the element applied.

Use soil tests to calculate conservative fertiliser rates. The Department of Agriculture and Food, Western Australia (DAFWA) has made available decision tools for nutrient management.

Managing the canopy

A bulky crop canopy and exposure of the upper pods may increase frost damage to pulses. Semi-leafless, erect peas may be more vulnerable than conventional, lodging types because their pods are more exposed. A mix of two varieties of differing height, maturity and erectness may also assist in reducing frost damage.

Sow in wider rows

Sowing wider rows may mean that frost is allowed to get to ground level, and the inter-row soil is more exposed. An open canopy does not trap cold air. Wide rows require the soil to be moist to trap the heat in the soil during the day. With wide or paired rows and a wide gap, the heat can radiate up, however this may not always be effective. This strategy may allow more airflow through crops, allowing soil heat to rise up to canopy height during frosts. Previous trial work has shown that wide-row sowing can have some effectiveness on both sandy and heavy-texture soil. However, there is a 1% yield loss per inch increase in row spacing and compromised weed control.

Channel cold air flow away from the susceptible crop by using wide rows aligned up and down the hill or slope. Where cold air settles, a sacrifice area may be required.

Stubble management

The presence of cereal stubble makes the soil cooler in the root zone, worsening the frost effect compared with bare soil. Standing stubble is considered less harmful than slashed stubble as less light is reflected and the soil is more exposed to the sun. Dark-coloured stubble will be more beneficial than light-coloured types. [11]

Sow a mixture of long season and short season varieties

This practice expands the period of flowering and different canopy heights may create a more undulating crop that could assist the emission of warm air from the soil to buffer cold temperatures around the crop heads on frost nights. Blending

11 Pulse Australia (2015) Minimising frost damage in pulses. Australian Pulse Bulletin. Updated 20 November, http://pulseaus.com.au/growing-pulses/publications/minimise-frost-damage

varieties is not usually recommended due to higher cost of seed, extra time required for sowing and the potential contamination of non-frosted grain from one variety with frosted grain from the other resulting in quality downgrading at delivery. To achieve the highest grade, grain from both varieties must be suitable for delivery to the same grade.

Lower sowing rates

A low sowing rate may allow a more open canopy. It also allows any heat in the soil to transfer to canopy height, reducing frost damage. This practice is not usually recommended but as the thinner crop is less competitive with weeds and crop yield potential is limited if a major frost event does not occur.

Cross sowing

Crops are sown twice with half the seed sown in each run producing an even plant density and generating a complete crop canopy that still allows air flow. Two trials across two seasons have been carried out in WA. In one trial a conventionally-sown wheat crop was compared with a cross-sown wheat crop at varying sowing rates. The conventionally sown crop experienced more frost damage and lower yields at all sowing rates compared with cross-sown crops. Cross sowing is not usually recommended due to the additional cost and time taken to sow the paddock twice and the minimum trial work that has been done to look at the impact of cross sowing. [12]

Roll sandy and loamy clay soil after seeding

This practice consolidates moist soil providing a reduced surface areas. This enables more radiant heat to be trapped and stored during the day compared with dry, loose soil. Moist and firm soil is a better conductor of heat and will cool slowly because heat removed at the surface by radiation is replaced in part by heat conducted upwards from the warmer soil below. A roller is usually towed behind the seeder machinery or it can be done post-emergent. Rolling is not usually recommended due to the extra expense, extra time required, inconsistent effectiveness, inter-row weed germination and increased wind erosion risk on susceptible soil types.

Rolling can help keep soils warm by slowing soil-moisture loss, but not necessarily on self-mulching or cracking soils. Note that press wheels roll only in the seed row, and not the inter-row. With no-till practice, avoid having bare, firm, moist soil as it will lose some of its stored heat.

Claying or delving sandy soils increases the ability of the soil to absorb and hold heat by making the soil colour darker, and retaining moisture nearer the surface.

Increase carbohydrate levels

Higher carbohydrate levels in the plant during frost leads to less leakage during thawing. A higher sugar content (high Brix) will also have a lower freezing point, and associated protection against frost damage. The effectiveness of various products applied to soil and plants to increase plant carbohydrates is unknown. [13]

A five-year research project funded by GRDC examined the effects of agronomic practices on frost risk in broadacre agriculture in southern Australia. The researchers manipulate the soil heat bank to store heat during the day and release heat into the canopy of the crop at night. The research examined how the crop canopy could be manipulated to allow for warm air from the soil to rise and increase the temperature at crop head height (Figure 5). [14]

12 B Biddulph. (2017). Frost and cropping. DAFWA. https://www.agric.wa.gov.au/frost/frost-and-cropping?nopaging=1

13 Pulse Australia (2015) Minimising frost damage in pulses. Australian Pulse Bulletin. Updated 20 November, http://pulseaus.com.au/growing-pulses/publications/minimise-frost-damage

14 M Rebbeck, G Knell (2007) Managing frost risk: a guide for southern Australian growers. SARDI, GRDC.

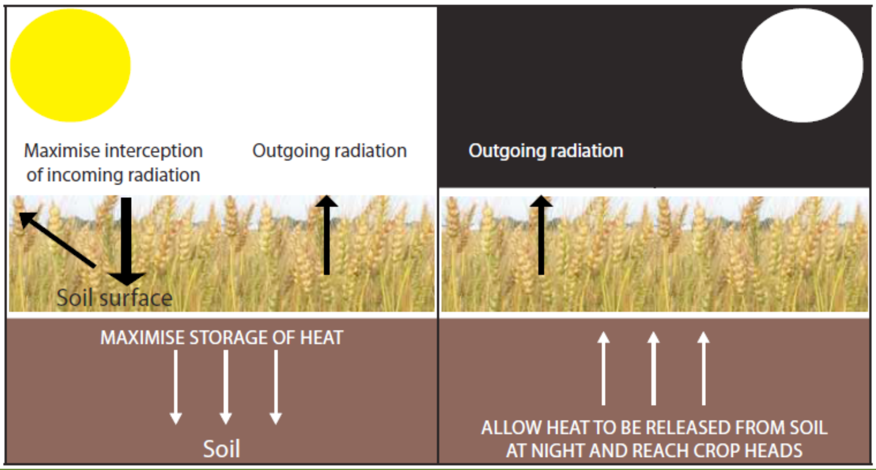

Figure 5: *Temperature dynamics in a crop canopy and canopy interactions.*

Source: Rebbeck and Knell 2007

Importance of soil moisture

Soil moisture is the most important factor for storing soil heat that will be released to and through the crop canopy at night. Because water has a high specific heat, radiation cooling overnight will be reduced when moisture is present in the soil. On a daily basis, heat is transferred into and out of approximately the top 300 mm of soil. When the soil is wet, heat transfer and storage in the upper soil layer is higher, so more heat is stored during daytime for release during the night.

There is also some evidence that moist soils can retain their warming properties for more than 24 hours, allowing some scope for an accumulation of heat from sunlight for more than one day. Heavier textured soils hold more moisture (and therefore heat) than lighter textured soils. Denser soil can hold more moisture within the soil surface for heat absorption and subsequent release. Darker soils also absorb more light energy than lighter soils. Water-repellent sandy soils are usually drier at the surface than normal soils, and are therefore more frost prone. Frost studies in SA have found that crops were likely to be more damaged on lighter soil types because the soil temperature is lower as a result of lower soil moisture and the more reflective nature of these soils. On such soils, clay spreading or delving may be an option for reducing frost risk. [15]

Breeding frost tolerance

Through Pulse Breeding Australia, the GRDC is investing in germ plasm enhancement and variety breeding to increase frost tolerance in pulses. The focus is on altered flowering time and duration to avoid frost, and screening of pulse varieties for relative levels of frost tolerance in the field. New varieties will be released when available. [16]

15 M Rebbeck, G Knell (2007) Managing frost risk: a guide for southern Australian growers. SARDI, GRDC.

16 Pulse Australia (2015) Minimising frost damage in pulses. Australian Pulse Bulletin. Updated 20 November, http://pulseaus.com.au/growing-pulses/publications/minimise-frost-damage

MORE INFORMATION

Managing frost risk – Eastern WA

Growing oaten hay for frost prone paddocks

WATCH: Managing the effects of Frost.

14.1.4 Managing frost affected crops

There are a number of options available for managing crops that have been frosted (e.g. Figure 6). Table 2 highlights these options and the pros and cons of each. The suitability of each option will be dependent on the severity of the frost and analysis costs versus returns. [17]

Table 2: *Options to manage frosted crops.*

Option	Advantages	Disadvantages
Harvest	No damage estimates required. Salvage remaining grain. Condition stubble for seeding	Costs may be greater than returns. Need to implement weed control. Threshing problems. Need to remove organic matter.
Hay/Silage	Stubble removed. Weed control.	Cost per hectare. Quality may be poor (especially wheat).
Chain/Rake	Retains some stubble and reduces erosion risk. Allows better stubble handling.	Cost per hectare. Time taken.
Graze	Feed value (Figure 6). Weed control.	Inadequate stock to utilise feed. Remaining grain may cause acidosis. Stubble may be difficult to sow into.
Spray	Stops weed seed set. Preserves feed quality for grazing. Gives time for decisions. Retains feed. Retains organic matter.	Difficulty getting chemicals onto all of the weeds with a thick crop. May not be as effective as burning. Boom height limitation. Cost per hectare. Some grain still in crop.

17 DAFWA (2016) Frost and cropping. https://www.agric.wa.gov.au/frost/frost-and-cropping

Option	Advantages	Disadvantages
Plough	Recycles nutrients and retains organic matter. Stops weed seed set. Green manure effect.	Requires offset discs to cut straw. Soil moisture needed for breakdown and incorporation of stubble.
Windrow	Stops weed seed set. Windrow can be baled. Regrowth can be grazed. Weed regrowth can be sprayed.	Relocation of nutrients to windrow. Low market value for straw. Poor weed control under swath. Cost per hectare.
Burn	Recycles some nutrients. Controls surface weed seeds. Permits recropping with disease control. Can be done after rain.	Potential soil and nutrient losses. Fire hazard. Organic matter loss.

Source: DAFWA

Figure 6: *Frosted pulses make excellent quality forage.*

Source: Pulse Australia

MORE INFORMATION

What to do with a frosted crop

14.2 Temperature

Both low and high temperatures can limit the growth and grain yield of chickpea at all phenological stages. Temperature is a major environmental factor regulating the timing of flowering thus influencing grain yield. The production of the cool season chickpea is constrained by low temperatures across much of its geographical range, including southern WA. Cold stress generally occurs in the late vegetative and reproductive stages across the geographical areas of chickpea production. Cold and freezing temperatures (-1.5°C–15°C) are considered a major problem during the seedling stage of winter-sown chickpea in Mediterranean-climate areas and autumn-sown crops in temperate regions. Southern Australia is most affected by chilling temperatures at flowering. On the other hand, high day and night temperatures (above 30/16°C) may cause damage during the reproductive stage on winter-sown chickpea in Mediterranean-climate areas or in season rainfall areas. [18]

Chilling and freezing range temperatures are one of the three most important abiotic stresses (frost, heat stress and drought) causing flower sterility and pod abortion. [19]

18 V Devasirvatham, DK Tan, PM Gaur, RM Trethowan (2014) Chickpea and temperature stress: An overview. Legumes under Environmental Stress: Yield, Improvement and Adaptations, 81.

19 A Maqbool, S Shafiq, L Lake (2010) Radiant frost tolerance in pulse crops—a review. Euphytica, 172(1), 1–12.

14.2.1 Impact of freezing range (below -1.5°C)

Freezing-sensitive plants are damaged or killed by temperatures below -1.5°C. Damage from freezing commonly occurs due to ice forming within the intercellular spaces. The rigid ice lattice structure extends with decreasing temperature and may penetrate cellular walls and membranes to an extent that is irreparable by normal cell processes.

The freezing tolerance of a plant varies greatly between different tissues—that is, upper and lower leaves of the plant canopy, stems, meristems, or roots. Tolerance to freezing range temperatures has been shown to decrease as the plant progresses from the seedling stage (most tolerant) to flowering (least tolerant).

Freezing stress predominantly occurs during the seedling and early vegetative stages of crop growth.

Prolonged periods of freezing range temperatures can prevent germination, reduce the vigour and vegetative biomass of the developing plant, and can be fatal to plants, especially those at the late vegetative and reproductive phenological growth stages.

The main effects of freezing temperatures on the developing seedling are related to membrane injury and include reduced respiration and photosynthesis and loss of turgor, resulting in wilting and temperature-induced drought stress. Some observations have indicated that freezing can reduce seed size and cause seed coat discolouration, probably due to stress conditions affecting the mobilisation of plant resources. [20]

14.2.2 Impact of chilling range (-1.5°C–15°C)

In chickpea, the upper limits of the chilling range are quite acceptable and even optimum for early growth in some genotypes, but the reproductive processes can become susceptible to damage from temperatures of ca. 15°C and lower.

In the Mediterranean-type environment of south-west Australia, chickpea yields are limited by chilling range temperatures during flowering, causing extensive flower and pod abortion. This is especially a problem for early sown crops aiming for high yield potential (high biomass) and for early flowering genotypes due to the abortion of flowers and pods in late winter and early spring, which in turn leads to low harvest index.

Desi chickpea seed can germinate in soil as cold as 5°C, but seedling vigour is greater if soil temperatures are at least 7°C. Kabuli chickpea seed is more sensitive to cold soils and should not be seeded into excessively wet soil or into soil with temperatures below 12°C at the placement depth.

In chickpea, sensitivity to freezing and chilling range temperatures increases as the plant progresses from germination to flowering. Temperatures within the chilling range can limit the growth and vigour of chickpea at all phenological stages, but are considered most damaging to yield at the reproductive stages. Southern Australia is most affected by chilling range temperatures at flowering.

A prolonged period of chilling range temperatures at any phenological stage of development in chickpea has detrimental effects on final seed yield. During germination, chilling range temperatures result in poor crop establishment, increased susceptibility to soil-borne pathogens, and reduced seedling vigour. At the seedling stage, long periods of chilling range temperatures can retard the growth of the plant and, in severe cases, cause plant death. Visual symptoms of chilling injury at the seedling stage can include the inhibition of seedling growth, accumulation of anthocyanin pigments, waterlogged appearance with browning of mesocotyls, and the browning and desiccation of coleoptiles and undeveloped leaves. At the vegetative stage, chilling range temperatures have a pronounced negative effect on plant growth and dry matter production. Less dry matter production

20 JS Croser, HJ Clarke, KHM Siddique, TN Khan (2003) Low-temperature stress: implications for chickpea (Cicer arietinum L.) improvement. Critical Reviews in Plant Sciences, 22(2), 185–219.

reduces the reproductive sink that the plant can support, which, in turn, reduces potential yield. Flower, pod, or seed abortion are further symptoms of chilling range temperatures (Figure 7).

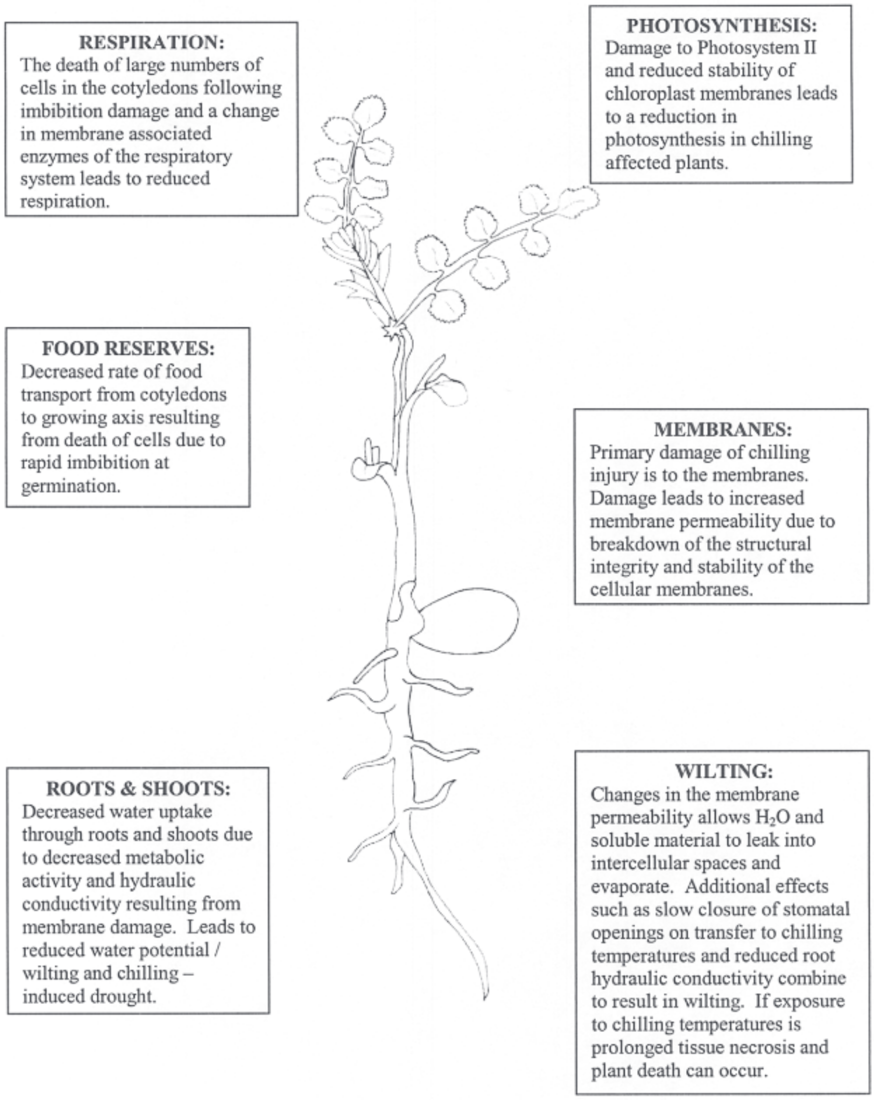

Figure 7: *Effect of chilling injury on chickpea at the seedling to vegetative phenological stage.*

Source: Croser et al. 2003

Chilling range temperatures at the mid to late vegetative stage retard growth rate and reduce plant vigour (Tables 3 and 4). These effects are due to the same mechanisms that affect post-emergent seedling growth—that is, reduced respiration and photosynthesis, and in severe cases a loss of turgor and subsequent water stress.

Air temperature and photoperiod have a major influence on the timing of reproductive events in chickpea, with the rate of progress to flowering being a linear function of mean temperature. Pollen germination and vigour is affected by chilling range temperatures. [21]

21 JS Croser, HJ Clarke, KHM Siddique, TN Khan (2003) Low-temperature stress: implications for chickpea (Cicer arietinum L.) improvement. Critical Reviews in Plant Sciences, 22(2), 185–219.

Table 3: *Effect of chilling range temperatures on Chickpea reproduction.*

Effect	Description
Flower shedding/floral abortion Pod shedding/drop	Sudden low temperatures (0° to 10°C) during flowering induces flower shedding, which causes partitioning of assimilates to vegetative growth, resulting in lowered Harvest Index. Major cause of low pod and seed set in subtropical South Asia and Australia.
Interrupted pollen tube growth	Temperatures up to 25°C shown to interrupt pollen tube growth. Failure of fertilisation results from poor germination and slow growth of pollen tubes in susceptible genotypes at low temperatures (Figure 4).
Lowered pollen viability	Pollen in tolerant genotypes more viable (90%) compared to susceptible genotypes (60%). Two stages of pollen sensitivity at 5 and 9 days before anthesis have been identified.
Reduced ovule size	Ovules in flowers opening on cool days were 9–45% smaller than warm day ovules – more pronounced in chilling susceptible than tolerant genotypes.
Reduced pistil size	Heterostyly – the distance between the anther and stigma at the time of flower opening is greater in sensitive than in tolerant genotypes.
Reduced stigmatic esterase activity	Reduced esterase activity was identified in susceptible genotypes suggesting the stigmas were less receptive to pollen tube growth.
Delayed anther dehiscence	Anther dehiscence is delayed by chilling temperatures, reducing fertilisation events.
Reduced pollen germinability	Possibly due to smaller amount of storage material in pollen from sensitive genotypes.
Reduced pollen turgor	Turgidity is an absolute requirement for germination. Pollen cells with leaking membranes cannot become turgid and germinate.

Source: Croser et al. 2003

Table 4: *Effect of chilling range temperatures at flowering on chickpea productivity at Merridin, Western Australia.* [22]

Date of planting	Date of 50% flowering	Mean daily temperature (°C) at 50% flowering	Number of aborted flowers (m^2)	Biological yield (t/ha^{-1})	Seed yield (t/ha^{-1})	Harvest Index
17 May	19 August	12.5	800	6.76	1.25	0.18
31 May	1 September	13.6	500	5.34	1.13	0.21
14 June	14 September	14.7	200	4.84	1.12	0.23
30 June	29 September	16.8	0	3.98	1.11	0.28
20 July	6 October	17.7	0	3.23	0.94	0.29

Source: Modified from Siddique and Sedgley (1983)

Exposure to prolonged periods of temperatures at the lower end of the chilling range can cause poor germination, slow growth, flower shedding and pod abortion, and in severe cases cell necrosis and plant death. The resulting yield penalty or reduction in harvest index varies dramatically in the field, but in some cases can be substantial (Figure 8).

22 KHM Siddique, C Marshall, RH Sedgley (1983) Temperature and leaf appearance in chickpea. Int. Chickpea Newsl. 8, 14–15

Figure 8: *Chilling damage in chickpea- sown paddock.*

Source: Pulse Breeding Australia

In Australia, flower shed and pod abortion due to chilling range temperatures at flowering is a major cause of poor yield. It should be noted that it is the combination of chilling range temperatures at flowering with terminal drought that is the cause of reduced seed yields in chickpea. Early sowing (winter) is essential in these environments in order to achieve high yield potential and avoid terminal soil moisture stress.

Desi types generally suffer less damage from low temperatures at germination than Kabuli types.

The development of cultivars with a higher degree of cold tolerance would facilitate the spread of chickpea growing regions to both higher altitudes and colder latitudes and therefore are worthy of considerable agronomic and breeding attention. [23]

Tolerance to low temperature

Low temperature at flowering is a major constraint to improving yields of chickpeas in many regions of the world. In particular, cool dryland environments such as that of south-western Australia would benefit from cultivars with the ability to flower and set pods early in the growing season before soil moisture becomes a limiting factor.

Desi types generally suffer less damage from low temperatures at germination than kabuli types. Research overseas and within Australia has demonstrated a range of cold tolerance among chickpea varieties. In parts of the world where chickpeas are grown as a spring crop because of the very cold winter, varieties have been developed that tolerate freezing conditions during vegetative growth. These varieties can be sown in autumn, survive over winter, and are ready to flower and set pods when temperatures rise in summer.

However, chickpea varieties resistant to low temperatures during flowering have not yet been found. Some genotypes from India are less sensitive than those currently grown in Australia, and these are being utilised in chickpea breeding programs at Department of Agriculture and Food, Western Australia (DAFWA) and the University of Western Australia (UWA).

Controlled environment studies at UWA have identified two stages of sensitivity to low temperature in chickpea. The first occurs during pollen development in the flower bud, resulting in infertile pollen even in open flowers. The second stage of sensitivity occurs at pollination when pollen sticks to the female style, and produces a tube that grows from the pollen down the style to the egg (Figure 9).

23 JS Croser, HJ Clarke, KHM Siddique, TN Khan (2003) Low-temperature stress: implications for chickpea (Cicer arietinum L.) improvement. Critical Reviews in Plant Sciences, 22(2), 185–219.

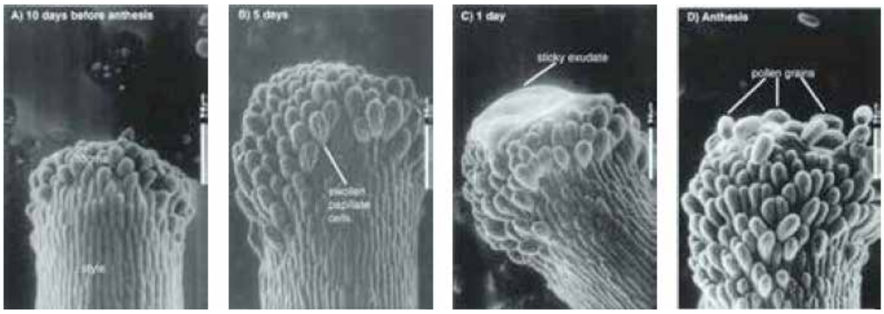

Figure 9: *Development of the style and stigma of chickpea flowers taken with an electron microscope.*

Photo: H Clarke. Source: UWA

At low temperatures pollen tubes grow slowly, fertilisation is less likely and the flower often aborts. The rate of pollen tube growth at low temperature is closely related to the cold tolerance of the whole plant. This trait can therefore be used to select more tolerant varieties (Figures 10).

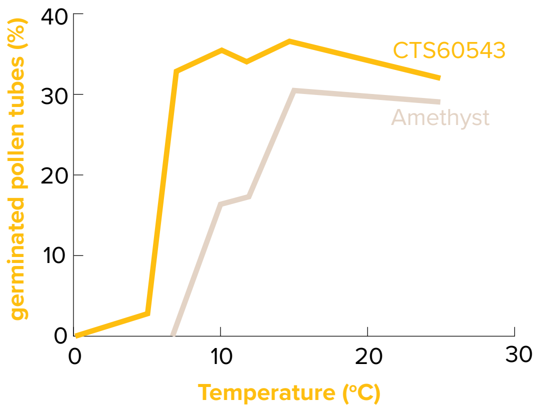

Figure 10: *Proportion of pollen germination at various temperatures in cold-sensitive (Amethyst) and cold-tolerant (CTS60543) varieties.* [24]

The critical average daily temperature for abortion of flowers in most varieties currently grown in Australia is about 15°C. New hybrids that set pods at ~13°C are being developed.

In the field, cold-tolerant varieties set pods about 1–2 weeks earlier than most current varieties. As well as conventional methods for plant improvement, DNA-based techniques are also being investigated. [25]

24 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

25 SC Sethi (1998) Improvement of cold tolerance and seed yield in chickpea. GRDC, DAFWA, UWA.

IN FOCUS

Response of chickpea genotypes to low-temperature stress during reproductive development

Clarke and Siddique (2004) demonstrated that temperatures of less than 15°C affect both the development and the function of reproductive structures in the chickpea flower. They studied aspects of the development of male and the female gametes and compared chilling-sensitive genotypes to identify the likely causes of flower abortion. They learned that, of all the aspects of reproduction, the function of pollen derived from chilling-sensitive plants is the most affected by low-temperature stress, and particularly the growth of the pollen tubes down the style before fertilisation occurs. In contrast, pollen tubes derived from chilling-tolerant plants continue to grow down the style under low-temperature stress. Although other stages of development and function, including the production of spores, pollen germination, and the stigma, were affected by low temperatures, none were correlated to the phenotype of the mother plant.

Having tested plants, the researchers then tested pollen.

Two periods of sensitivity to low temperature were identified during pollen development (sporogenesis) in both Amethyst (cold tolerant) and CTS60543 (cold sensitive), each of which resulted in chilling-stressed plants having flowers with only 50% viable pollen (Figure 11a). The chilling treatment of 3°C was assumed to be below the base temperature for growth in chickpeas. As a result, those flowers that flowered 'n' days after the end of chilling would have been stressed 'n' days before anthesis. On this basis, they estimated that the first stage of sensitivity occurred nine days before anthesis. The significant decrease in pollen viability coincided with lower podset (approximately 70%) in both genotypes. This was followed by a recovery in pollen viability and podset.

The second period of sensitivity occurred 4–6 days before anthesis. In Amethyst a dramatic drop to 40% podset correlated with the decrease in pollen viability (Figure 11b), while normal pods formed at other nodes before and after this chilling-sensitive stage. Despite lower pollen viability in CTS60543, podset was not affected at this time, and all of the flowers gave rise to full pods in this genotype.

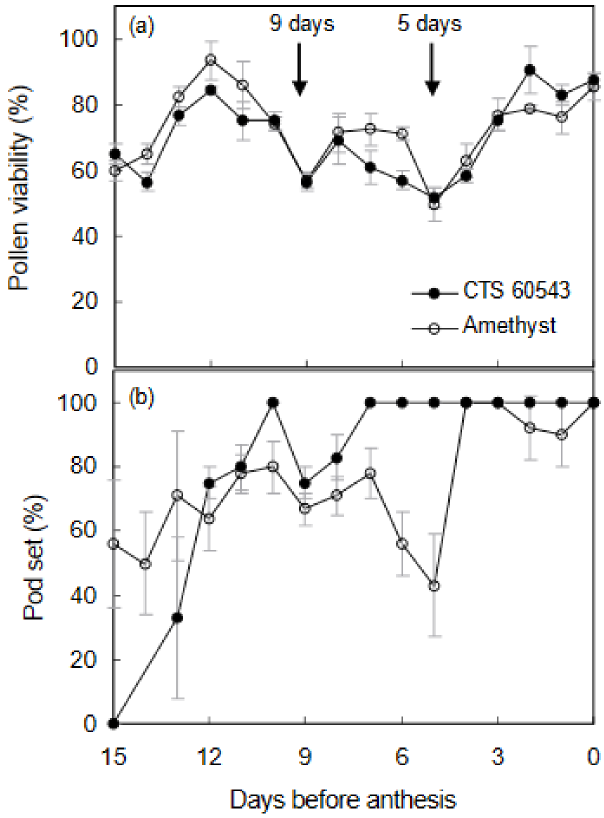

Figure 11: *The effects of stressing plants with a temperature of 3°C during flower development in tolerant (CTS60543) and sensitive (Amethyst) genotypes. (A) Pollen viability. (B) Podset. Arrows indicate susceptible periods at 9 days and 5–6 days before anthesis.*

Temperatures from 7–25°C did not affect the proportion of pollen grains which germinated after four-hour incubation in vitro, and 80–90% germination occurred in all of the genotypes examined (Figure 12). The percentage that germinated was significantly lower at 3°C than at other temperatures, but no significant difference was measured between genotypes at this temperature when samples were examined at four hours.

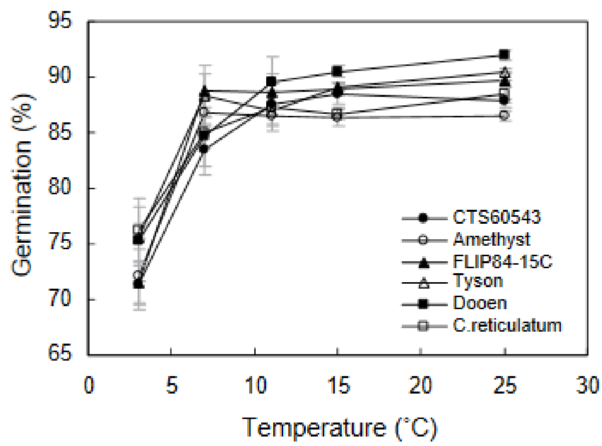

Figure 12: *The effect of temperature on pollen germination in chickpea genotypes after four-hour culture in lab conditions.*

A second experiment was therefore designed to examine the rate of germination with selected genotypes at 3°C in the period up to four hours in vitro. The researchers found that low temperature delayed the onset of germination by 20–40 minutes compared to the control at 25°C, and it decreased the rate at which the pollen germinated (Figure 13). No significant difference was measured in germination between genotypes in the first 40 minutes in culture. After this time the percentage that germinated was significantly different between genotypes.

However, no link was observed between the rate of pollen germination in vitro at 3°C and the chilling tolerance of the whole plant. In fact, pollen from CTS60543 was slightly slower to begin germination.

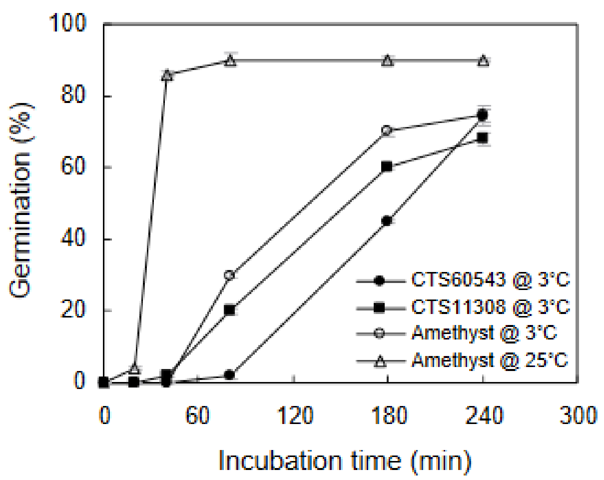

Figure 13: *Rate of pollen germination during 4 hour culture in lab conditions at low temperature (3°C) in sensitive and tolerant genotypes.*

Figure 14 illustrates a greater number of pollen tubes in the style in CTS60543 compared to Amethyst when hand-pollinated plants are stressed at 7°C for 24 h after pollination. [26]

26 HJ Clarke, KHM Siddique (2004) Response of chickpea genotypes to low temperature stress during reproductive development. Field Crops Research 90 (2), 323–334.

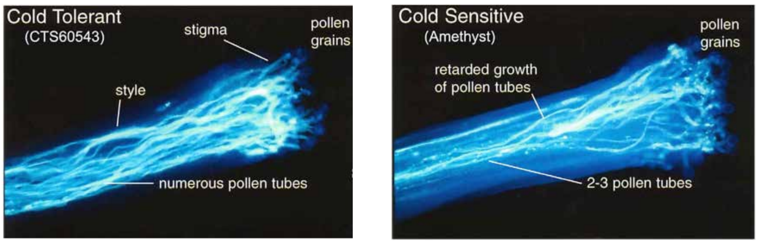

Figure 14: *More pollen tubes of CTS60543 grow down the style to the ovary at low temperature stress (7°C) compared to Amethyst. Styles were fixed 24 h after pollination and stained with aniline blue.* [27]

14.2.3 Heat stress

High temperature stress in chickpea causes substantial loss in crop yield due to damage to reproductive organs, increased rate of plant development, and reduced length of the reproductive period (Figure 15). [28]

Figure 15: *Chickpea varieties planted under hot conditions: heat sensitive plant with no pods (left) and heat tolerant plant with healthy pods (right).*

Photo: Daniel Tan. Source: Foodmag

In its reproductive stage chickpea is sensitive to heat stress (20°C or higher as day/night temperatures) with consequent substantial loss of potential yields at high temperatures. The anthers of heat sensitive genotypes have been found to have reduced synthesis of sugars due to inhibition of the appropriate enzymes. Consequently, effected plant pollen can have considerably lower sucrose levels resulting in reduced pollen function, impaired fertilisation and poor pod set in the heat sensitive genotypes.

27 HJ Clarke, KHM Siddique (2004) Response of chickpea genotypes to low temperature stress during reproductive development. Field Crops Research 90 (2), 323–334.

28 Y Gan, J Wang, SV Angadi, CL McDonald (2004) Response of chickpea to short periods of high temperature and water stress at different developmental stages. In Proceedings of the 4th International Crop Science Congress, Brisbane, 26–08..

IN FOCUS

Heat-stress-induced reproductive failures in chickpea are associated with impaired sucrose metabolism in leaves and anthers.

The physiological mechanisms associated with reproductive failures caused by heat stress have not been established. Researchers screened a large core-collection of chickpea against heat stress and identified two heat-tolerant (ICC15614, ICCV. 92944) and two heat-sensitive (ICC10685, ICC5912) genotypes. These four genotypes were sown during the normal time of sowing and also late, to expose them to heat stress (above 32/20°C) during reproductive stage. In the heat-stressed plants, phenology accelerated as days to flowering and podding, and biomass decreased significantly. The significant reduction in pod set (%) was associated with reduced pollen viability, pollen load, pollen germination and stigma receptivity in all four genotypes. Heat stress inhibited pollen function more in the sensitive genotypes than in the tolerant ones, and consequently showed significantly less pod set. Heat stress significantly reduced stomatal conductance, leaf water content, chlorophyll, membrane integrity and photochemical efficiency with a larger effect on heat-sensitive genotypes. The inhibition of important enzymes was significantly greater in the heat-sensitive genotypes. Concurrently, the anthers of these genotypes had significantly less enzymatic activity and therefore sucrose content. As a result, pollen had considerably lower sucrose levels, resulting in reduced pollen function, impaired fertilisation and poor pod set in heat-sensitive genotypes. [29]

Chickpea pollen grains are more sensitive to heat stress than the stigma. High temperatures have been found to reduce pollen production per flower, amount of pollen germination, pod set and seed number (Figure 16). [30]

Figure 16: *Comparison of seed size under heat stress. Larger seeds (left side) from non-stressed and smaller seeds (right side) from heat-stressed conditions.*

Photo: V Devasirvatham. Source: Devasirvatham et al. (2014)

Heat stress during the reproductive stage can cause significant yield loss. Very little of the germplasm will set pods when temperatures exceed 36°C. During the

29 N Kaushal, R Awasthi, K Gupta, P Gaur, KH Siddique, H Nayyar (2013) Heat-stress-induced reproductive failures in chickpea (Cicer arietinum) are associated with impaired sucrose metabolism in leaves and anthers. Functional Plant Biology, 40(12), 1,334–1,349.

30 V Devasirvatham, PM Gaur, N Mallikarjuna, RN Tokachichu, RM Trethowan, DK Tan (2012) Effect of high temperature on the reproductive development of chickpea genotypes under controlled environments. Functional Plant Biology, 39(12), 1,009–1,018.

reproductive stage, heat stress can cause male and female floral organ development to be timed differently and impair formation, resulting in lower yields. [31]

14.2.4 Heat and water stress

The combination of environmental stresses can also impact chickpea yield.

IN FOCUS

Response of chickpea to short periods of high temperature and water stress at different developmental stages.

A study was conducted to determine the effect of short periods of high temperature and water stress on pod production, seed set and yield of chickpea (see Figure 17 for results). Desi and Kabuli chickpea were grown in growth chambers under 20/16°C day/night temperatures, as a control treatment. High (35/16°C) and low (28/16°C) temperature stress was imposed for 10 days during flower and pod development. Simultaneously, high (plants remained at 50% available water) and low (at 90% available water) water stress was also imposed. Plants stressed at 35/16°C during flowering produced 53% fewer fertile pods on the mainstem and 22% fewer pods on the branches than those kept at 20/16°C. Nearly 90% of the pods formed during stress were infertile. Due to high temperature stress, kabuli crop filled 58% of the pods formed and decreased seeds pod by 26% from the check. Consequently, desi chickpea seed yield decreased by 54% when stressed during pod development and 33% when stressed during flowering. Kabuli chickpea seed yield decreased by 50% when stressed during pod formation and 44% when stressed during flowering. Shortening the stress period during reproductive development may increase the yield potential of chickpea. [32]

31 V Devasirvatham, DKY Tan, PM Gaur, TN Raju, RM Trethowan (2012) High temperature tolerance in chickpea and its implications for plant improvement. Crop and Pasture Science, 63(5), 419–428.

32 Y Gan, J Wang, SV Angadi, CL McDonald (2004) Response of chickpea to short periods of high temperature and water stress at different developmental stages. In Proceedings of the 4th International Crop Science Congress, Brisbane, 26–08.

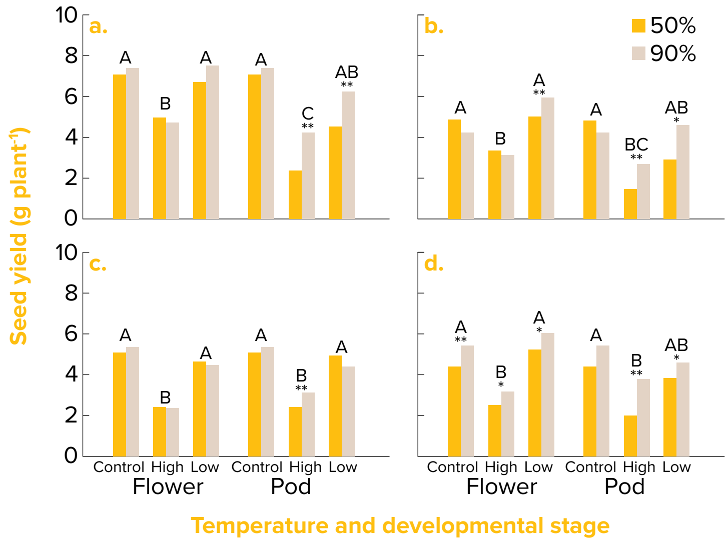

Figure 17: *Seed yield per plant produced by a) desi, b) large-seeded kabuli, c) small-seeded kabuli (small seed from previous year), and d) small-seeded (small seed from a small-seeded crop in the previous four years) chickpea stressed at high (35/16 °C) and low (26/16 °C) temperature during flower and pod developmental stages in comparison with no-stress control (20/16 °C). *, ** represent significant at P<0.05 and P<0.01, respectively, between low (90% available water) and high (50% available water) water stress treatments. Bars with the same capital letters did not differ among the temperature stress treatments at a given crop developmental stage.* [33]

14.3 Waterlogging/flooding issues for chickpeas

Chickpeas are particularly sensitive to waterlogging during flowering and podding.

Waterlogging occurs when there is too much water in the plant's root zone, which results in the roots not being able to access enough oxygen for respiration. Waterlogging, when it occurs, is a major constraint to production. Plant growth is affected, and under certain conditions will even lead to premature plant death.

Landholders may not realise a site is waterlogged until water appears on the soil surface (inundation).

Almost two-thirds of the agricultural land in the south west region of Western Australia has a duplex soil profile with sandy loam surface soils overlying sandy clay subsoils. These soils are susceptible to waterlogging when the amount of rainfall exceeds the ability of the soil to drain away excess moisture. This is exacerbated by the strong texture-contrast between the top and the subsoil, which allows more infiltration to the topsoil than can be transmitted by the subsoil.

33 Y Gan, J Wang, SV Angadi, CL McDonald (2004) Response of chickpea to short periods of high temperature and water stress at different developmental stages. In Proceedings of the 4th International Crop Science Congress, Brisbane, 26–08.

As there are no in-crop control measures to deal with waterlogging, a critical management tool is avoidance of high-risk paddocks (based on previous experience and paddock history) (Figure 18). [34]

Figure 18: *Water logging in chickpeas.*

Source: Australian UAV

14.3.1 Symptoms

Key points:

- plants most susceptible to waterlogging at flowering and early pod fill
- symptoms develop within 2 days of flooding
- roots not rotted and are not easy to pull out
- plants turn yellow/brown to reddish colour (Figure 19)
- leaflets are held upright and leaf edges turn yellow
- lower leaves defoliate
- plants die very fast (Figure 20) [35]

Figure 19: *Lower leaves on plants show marginal yellowing of leaflets (left). Mild waterlogging event with yellowing of leaves and roots intact with little discolouration (right).*

Source: QDAF in CropIT.

34 K Moore, M Ryley, M Sharman, J van Leur, L Jenkins, R Brill (2013) Developing a plan for chickpeas in 2013. GRDC Update Papers February 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Developing-a-plan-for-chickpeas-2013

35 CropIT. Chickpea – Waterlogging. http://www.cropit.net/?q=content/environment/waterlogging-0

Figure 20: *Severely waterlogged plants die rapidly when waterlogged during and after pod fill.*

Source: QDAF in CropIT.

Chlorosis has been observed after four days of waterlogging, firstly on the upper leaves. Reddish-brown anthocyanin pigmentation also develops on midribs, stems and some leaflets. Leaflets fold upward, a symptom typical of moisture stress. Unexpanded leaves have necrotic margins. Abscission of chlorotic leaflets can begin six days after waterlogging and progress until most of the plant is defoliated. [36]

Effect of waterlogging on stomatal conductance and photosynthesis

Stomatal conductance is the measure of the rate of passage of carbon dioxide (CO_2) entering or water vapor exiting through the stomata of a leaf, and photosynthesis is a process that converts light energy into chemical energy that can fuel growth. Within 24 hours, stomatal conductance of waterlogged chickpea can decline, and can completely stop within three days. One day after waterlogging, photosynthesis and stomatal conductance has been recorded at 87% and 36%, respectively, of unaffected plants. Rapid decline in stomatal conductance over 24 hours, followed by a sharp decrease in photosynthesis between two and four days, suggests that waterlogging decreases photosynthesis through stomatal closure. Stomatal closure may be caused by a decrease in potassium uptake, or production of abscisic acid or ethylene by the plant. Reduction in photosynthesis may result from the effects of waterlogging on carboxylation enzymes and the loss of chlorophyll, in addition to the effect of stomatal closure. [37]

36 AL Cowie, RS Jessop,DA MacLeod (1989) Effect of waterlogging on photosynthesis and stomatal conductance of chickpea leaves. 5th Aust. Agron. Conf.©, University of New England.

37 AL Cowie, RS Jessop,DA MacLeod (1989) Effect of waterlogging on photosynthesis and stomatal conductance of chickpea leaves. 5th Aust. Agron. Conf.©, University of New England.

IN FOCUS

Effects of waterlogging on chickpeas: influence of timing of waterlogging.

The effect of the timing of waterlogging on chickpeas was examined in two pot trials. Plants were waterlogged for ten days from 21 days after sowing (DAS), at flowering or at mid-pod fill, plus combinations of these times. Waterlogging at any stage reduced seed yield; waterlogging at 21 DAS had the least effect, reducing yield relative to the non-waterlogged control by 35%. Ability of the plant to survive and regrow following waterlogging decreased with increasing physiological age: mortality rate averaged 0, 30 and 100% after waterlogging at 21 DAS, flowering and pod fill, respectively (Table 5). Tolerance to waterlogging was not enhanced by previous exposure to waterlogging. In the second experiment, waterlogging was imposed at six different times shortly before or after flowering began. Ability to survive waterlogging declined sharply as flowering commenced: mortality rate increased from 13% when waterlogging was imposed six days before flowering to 65% one day after flowering, and 100% when waterlogging began 7.5 days after flowering (Table 5). The researchers suggest that survival and recovery after waterlogging may have been inhibited in flowering plants by an inadequate supply of nitrogen or carbohydrates. [38]

Table 5: *Mortality rate and regrowth following waterlogging imposed at five stages of floral development. Means followed by the same letter are not significantly different.*

Planting times	1	2	3	4	5
Time of waterlogging (days after sowing)	66	61	56	51	46
Time of flowering (days after waterlogging)	-7.5	-6	-1	+2	+6
Mortality rate (%)	100a	94a	63b	38c	13d
Total regrowth per pot (mg dry weight)	0a	0.4ab	18.1bc	32.6c	50.6d

Source: Cowie et al. (1996)

14.3.2 Management options for waterlogging

Key points:

- There is no in-crop treatment for waterlogging
- Avoid poorly drained paddocks and those prone to waterlogging.
- Use raised beds
- Use short duration flows under irrigation
- Do not flood-irrigate after podding has commenced, especially if the crop has been stressed.

38 AL Cowie, RS Jessop,DA MacLeod (1989) Effect of waterlogging on photosynthesis and stomatal conductance of chickpea leaves. 5th Aust. Agron. Conf.©, University of New England.

A rule of thumb is that if the crop has started podding and the soil has cracked, do not irrigate. Overhead irrigation is less likely to result in waterlogging, but consult your agronomist. [39]

Drainage can be improved on many sites and is the first thing to consider once a waterlogging problem has been identified. Options might vary from shallow surface drains (i.e. Spoon- and 'W'-drains) to more intensive drainage using wide-spaced furrows, to the intensive drainage form of raised beds.

Identifying problem areas

The best way to identify problem areas is to dig holes about 40 cm deep in winter and see if water flows into them (Figure 21). If it does, the soil is waterlogged. Digging holes for fence posts often reveals waterlogging.
Some farmers put slotted PVC pipe into augered holes. They can then monitor the water levels in their paddocks.
Symptoms in the crop of waterlogging include:

- Yellowing of crops and pastures.
- Presence of weeds such as toad rush, cotula, dock and Yorkshire fog grass. [40]

Figure 21: *Water fills hole while digging in waterlogged soil.*

Source: Soilquality.org

Raised bed scan overcome waterlogging

In most cases, drainage with or without raised beds are the best way to overcome waterlogging and inundation in most areas. A network of shallow drains in cropped areas pay for themselves within a few years. Where drains can only partially overcome the problem, changes to crop species, varieties and management may be necessary. [41]

14.4 Drought stress

Chickpea is an important winter pulse crop for the neutral-to-alkaline heavy textured soils in both the Mediterranean climatic region and summer-rainfall region of Australia, including WA. Chickpea growing regions of WA generally experience cool wet winters, whereas in spring, increasing temperatures and reduced rainfall result in a terminal drought situation for most crops. Unlike many other crops, chickpea is unable to escape this terminal drought through rapid development because

39 K Moore, M Ryley, M Schwinghamer, G Cumming, L Jenkins (2011) Chickpea: Phytophthora root rot management. Northern Pulse Bulletin. Pulse Australia, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot

40 D Bakker. Soilquality.org. Waterlogging Factsheet. http://soilquality.org.au/factsheets/waterlogging

41 D Bakker. (2014). Overcoming waterlogging. DAFWA. https://www.agric.wa.gov.au/soil-management/overcoming-waterlogging

low temperatures (<15°C) often cause flower and pod abortion, especially in cool southern areas. [42]

Yield losses can be the result of intermittent drought during the vegetative phase, due to drought during reproductive development or due to terminal drought at the end of the crop cycle. [43]

After disease, the major constraint to greater chickpea production is its sensitivity to the end-of-season drought that occurs in both the Mediterranean-type climates and when grown on stored soil moisture in the summer-rainfall region of Australia. Terminal drought occurs in the Mediterranean-type climates because they are dependent on rainfall and in spring, rainfall decreases and evaporation increases when chickpea enters its reproductive stage. The summer-rainfall regions are more dependent on the stored soil moisture and terminal drought occurs because the soil moisture is exhausted during the seed-filling stage.

Terminal drought reduces leaf photosynthesis in chickpea before seed growth commences so that seed filling is, in part, dependent on carbon and nitrogen accumulated prior to podding. For example, under terminal drought, more than 90% of the seed nitrogen in chickpea comes from pre-podding sources, particularly leaves. [44]

IN FOCUS

Response of chickpea to terminal drought: leaf stomatal conductance, pod abscisic acid concentration, and seed set, in WA.

Flower and pod production and seed set of chickpea are sensitive to drought stress. A two-fold range in seed yield was found among a large number of chickpea genotypes grown at three dryland field sites in south-western Australia. Leaf water potential, photosynthetic characteristics, and reproductive development of two chickpea genotypes with contrasting yields in the field were compared when subjected to terminal drought in 106 kg containers of soil in a glasshouse. The terminal drought imposed from early podding reduced biomass, reproductive growth, harvest index, and seed yield of both genotypes. Terminal drought at least doubled the percentage of flower abortion, pod abscission, and number of empty pods. Pollen viability and germination decreased when the fraction of transpirable soil water (FTSW) decreased below 0.18 (82% of the plant-available soil water had been transpired); however, at least one pollen tube in each flower reached the ovary. The young pods that developed from flowers produced when the FTSW was 0.50 had viable embryos, but contained higher abscisic acid (ABA) concentrations than those of the well-watered plants; all pods ultimately aborted in the drought treatment. Cessation of seed set at the same soil water content at which stomata began to close and ABA increased strongly suggested a role for ABA signalling in the failure to set seed either directly through abscission of developing pods or seeds or indirectly through the reduction of photosynthesis and assimilate supply to the seeds. [45]

42 RJ Jettner, SP Loss, KHM Siddique, RJ French (1999) Optimum plant density of desi chickpea (Cicer arietinum L.) increases with increasing yield potential in south-western Australia. Crop and Pasture Science, 50(6), 1,017–1,026.

43 A Mafakheri, A Siosemardeh, B Bahramnejad, PC Struik, Y Sohrabi (2010) Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. Australian journal of crop science, 4(8), 580.

44 JA Palta, AS Nandwal, S Kumari, NC Turner (2005) Foliar nitrogen applications increase the seed yield and protein content in chickpea (Cicer arietinum L.) subject to terminal drought. Crop and Pasture Science, 56(2), 105–112.

45 J Pang, NC Turner, T Khan, YL Du, JL Xiong, TD Colmer, KH Siddique (2016) Response of chickpea (Cicer arietinum L.) to terminal drought: leaf stomatal conductance, pod abscisic acid concentration, and seed set. Journal of experimental botany, erw153.

Drought after podding is a common feature of chickpea production in south-western Australia. One study investigated the effect of water stress, imposed after podding, on yield and on the accumulation of amino acids and soluble sugars in seeds. Although terminal water stress decreased the total plant dry mass and seed yield by 23% and 30% respectively, it had no effect on the mass of individual pods and seeds, which remained on the plant after the imposition of stress treatment. The deleterious effect of water stress on yield was due to increased pod abortion and a decrease in pod formation. Water stress improved the seed's nutritive value in terms of higher accumulation of soluble sugars, amino acids and proteins. [46]

Plants grown under drought condition have a lower stomatal conductance in order to conserve water. Consequently, CO_2 fixation is reduced and photosynthetic rate decreases, resulting in less assimilate production for growth and yield of plants. Drought stress during vegetative growth or anthesis significantly decreases chlorophyll and therefore photosynthesis. Drought stress at anthesis phase can reduce seed yield more severely than during vegetative stage. [47]

Water stress can impact light interception and light use efficiency by affecting chickpea development during leaf expansion. Therefore, the timing of water stress conditions during chickpea canopy development will determine whether the plant experiences poor light interception or light use efficiency. [48]

IN FOCUS

Physiological responses of chickpea genotypes to terminal drought in a Mediterranean-type environment, WA.

Two field experiments were carried out to investigate the effects of terminal drought on chickpea grown under water-limited conditions in the Mediterranean-climatic region of Western Australia. In the first experiment, five sesi chickpeas and one kabuli chickpea were grown in the field with and without irrigation after flowering. In the second experiment, two desi and two kabuli cultivars were grown in the field with either irrigation or under a rainout shelter during pod filling. Leaf water potential (ψl), dry matter partitioning after pod set and yield components were measured in both experiments while growth before pod set, photosynthesis, pod water potential and leaf osmotic adjustment were measured in the first experiment only. In the first experiment, total dry matter accumulation, water use, both in the pre- and post-podding phases, ψl and photosynthesis did not vary among genotypes. In the rainfed plants, ψl decreased below −3 MPa while photosynthesis decreased to about a tenth of its maximum at the start of seed filling. Osmotic adjustment varied significantly among genotypes. Although flowering commenced from about 100 days after sowing (DAS) in both experiments, pod set was delayed until 130–135 DAS in the first experiment, but started at 107 DAS in the second experiment. Water shortage reduced seed yield by 50-80%, due to a reduction in seed number and seed size. Apparent redistribution of stem and leaf dry matter during pod filling varied from 0-60% among genotypes, and suggests that this characteristic may be important for a high harvest index and seed yield in chickpea. [49]

46 MH Behboudian, Q Ma, NC Turner, JA Palta, (2001) Reactions of chickpea to water stress: yield and seed composition. Journal of the Science of Food and Agriculture, 81(13), 1,288–1,291.

47 A Mafakheri, A Siosemardeh, B Bahramnejad, PC Struik, Y Sohrabi (2010) Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. Australian journal of crop science, 4(8), 580.

48 S Fukai, GL Hammer (1995) Growth and yield response of barley and chickpea to water stress under three environments in southeast Queensland. II. Root growth and soil water extraction pattern. Crop and Pasture Science, 46(1), 35–48.

49 L Leport, NC Turner, RJ French, MD Barr, R Duda, SL Davies, KHM Siddique (1999) Physiological responses of chickpea genotypes to terminal drought in a Mediterranean-type environment. European Journal of Agronomy, 11(3), 279–291.

14.4.1 Managing for drought

Long-term historical records indicate that our climate is becoming progressively warmer and dryer. This trend is expected to continue due to increased levels of greenhouse gas in the atmosphere, with dry seasons likely to become more frequent over southern Western Australia. DAFWA has developed a Climate Change Response Strategy to focus its work in climate change on those areas of highest importance. The strategy identifies a range of actions including mitigation, sequestration, adaptation and governance, and rates them according to when the actions should be completed and the priority of the action. DAFWA provides data and information on current seasonal climate through its network of automatic weather stations and seasonal climate forecasts through the Statistical Climate Information system. In dry years, DAFWA provides a set of actions and information to assist growers and agribusiness in the management of seasonal conditions and their consequences. [50]

For crops exposed to terminal drought, the application of nitrogen fertiliser to the soil during pod set and seed filling is unlikely to assist in delaying the withdrawal of nitrogen from the leaves and maintaining leaf photosynthesis because nitrogen is not taken up from dry soil. However, foliar applications of urea have been effective in increasing the nitrogen availability for seed filling. [51]

IN FOCUS

Foliar nitrogen applications increase the seed yield and protein content in chickpea subject to terminal drought

In this study, it was hypothesised that foliar application of urea may increase nitrogen availability for seed filling in chickpea grown under terminal drought. The effect of foliar application of isotopically labelled nitrogen (15N-urea) at four stages during flowering and podding on the uptake and utilisation of nitrogen by chickpea (*Cicer arietinum* L.) under conditions of terminal drought was investigated in a glasshouse study. Five treatments were used to investigate the effect of timing of foliar application of urea, equivalent to 30 kg N/ha, on the uptake and utilisation of nitrogen for biomass, yield, seed protein content, and seed size: foliar application at (*i*) first flower, (*ii*) 50% flowering, (*iii*) 50% pod set, and (*iv*) the end of podding, and (*v*) an unsprayed control treatment. Terminal drought was induced from pod set onward, resulting in a rapid development of plant water deficits (–0.14 MPa/day) and a decrease in leaf photosynthesis irrespective of the timing of foliar urea application. Foliar applications of urea at first flower and at 50% flowering, before terminal drought was induced, increased yield and seed protein content. The increase in yield resulted from an increase in the number of pods with more than one seed rather than from increased pod number per plant or increased seed size, indicating greater seed survival under terminal drought. Also, the increase in the seed protein content resulted from increased nitrogen availability for seed filling. Foliar application of urea during flowering, before terminal drought was induced, resulted in 20% more biomass at maturity, suggesting that growth prior to the development of water shortage increased the carbon resources for sustained seed filling under conditions of terminal drought. Foliar applications of urea at 50% pod set and at the

50 DAFWA. Drought. https://www.agric.wa.gov.au/climate-land-water/climate-weather/drought

51 JA Palta, AS Nandwal, S Kumari, NC Turner (2005) Foliar nitrogen applications increase the seed yield and protein content in chickpea (Cicer arietinum L.) subject to terminal drought. Crop and Pasture Science, 56(2), 105–112.

end of podding did not affect the yield or seed protein content, primarily because the uptake of nitrogen was limited by the leaf senescence that occurred with the development of terminal drought. The results indicate the potential to increase yields of chickpea by application of foliar nitrogen near flowering in environments in which terminal droughts reduce yield. [52]

WATCH: Over the Fence west: Cost focus keeps profits up in drying climate.

14.4.2 Adaptation to drought stress

There are three strategies of crop adaptation to drought-stressed environments, all of which are useful in the Mediterranean climate of WA:

1. Drought escape, where the crop completes its life cycle before the onset of terminal drought.
2. Drought avoidance, where the crop maximises its water uptake and minimises is water loss.
3. Drought tolerance, where the crop continues to grow and function at reduced water contents. [53]

In all environments except in northern WA, chickpea is grown through the winter and spring as a rainfed crop and suffers from water shortage during seed development in spring. Despite a wide environmental range, many of the same cultivars are used across the country. The basis of the wide adaptation in chickpea is important as new cultivars are developed.

Chickpea may adapt to drought stress by maximising its water uptake through continuous root growth up to seed filling and by maintaining substantial water uptake until the fraction of extractable moisture in the root profile falls to 0.4. [54] In addition to these strategies, early sowing of chickpeas in south-western Australia develops a large green area and rapid ground cover, absorbs a significant proportion of photosynthetic-active radiation early in the season when vapour pressure deficits are low, and uses more water in the post-flowering period. [55] Consequently, such

52 JA Palta, AS Nandwal, S Kumari, NC Turner (2005) Foliar nitrogen applications increase the seed yield and protein content in chickpea (Cicer arietinum L.) subject to terminal drought. Crop and Pasture Science, 56(2), 105–112.

53 Ludlow, M. M. (1989). Strategies of response to water stress. Structural and functional responses to environmental stresses, 269–281.

54 KHM Siddique, RH Sedgley (1987) Canopy development modifies the water economy of chickpea (Cicer arietinum L.) in south-western Australia. Crop and Pasture Science, 37(6), 599–610.

55 (Keatinge and Cooper 1983; Loss et al. 1997; Singh et al. 1997; Thomson and Siddique 1997; Siddique et al. 1997) as cited in H Zhang, M Pala, T Oweis, H Harris (2000) Water use and Water Use Efficiency of chickpea and lentil in a Mediterranean environment. Crop and Pasture Science, 51(2), 295–304.

crops produce large biomass and grain yield. Application of supplemental irrigation at flowering and early pod-filling can relieve drought stress and substantially increase seed yield. [56]

Plants can partly protect themselves against mild drought stress by accumulating osmolytes. Proline is one of the most common compatible osmolytes in drought-stressed plants. Proline does not interfere with normal biochemical reactions but allows the plants to survive under stress. More drought tolerant varieties have a greater capacity to accumulate proline and buffer the effects of drought than sensitive varieties. [57]

One study found that a strain of symbiotic rhizobia (nitrogen-fixing bacteria) was effective in root-nodule symbiosis, partially alleviated decreased growth and yield, and increasing root biomass of chickpeas under drought stress. [58]

IN FOCUS

The role of phenology in adaptation of chickpea to drought

Chickpea is grown from autumn to early summer in both Mediterranean-type climates with winter dominant rainfall and on stored soil moisture in sub-tropical climates with summer-dominant rainfall. In both types of environment, water shortages can occur at any time during the growing season, but terminal drought predominates. A study conducted over a two-year period with a common set of 73 genotypes showed that high-yielding genotypes flowered early, podded early and had a relatively long flowering period at most, but not all, low-yielding sites. Thus drought escape was an important phenological characteristic at sites with terminal drought. However, these characteristics did not predominate at a site in which the drought was severe throughout the growth period. Studies under rainfed conditions at a dry site in Western Australia have shown that a high degree of biomass redistribution from leaves to stems to the pod is associated with high yield, suggesting that physiological mechanisms in addition to rapid phenological development play a role in the adaptation of chickpea to water-limited environments. [59]

56 H Zhang, M Pala, T Oweis, H Harris (2000) Water use and Water Use Efficiency of chickpea and lentil in a Mediterranean environment. Crop and Pasture Science, 51(2), 295–304.

57 A Mafakheri, A Siosemardeh, B Bahramnejad, PC Struik, Y Sohrabi (2010) Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. Australian journal of crop science, 4(8), 580.

58 A Bano, R Batool, F Dazzo (2010) Adaptation of chickpea to desiccation stress is enhanced by symbiotic rhizobia. Symbiosis, 50(3), 129–133.

59 J Berger, NC Turner, RJ French (2003) The role of phenology in adaptation of chickpea to drought. In Solution for a better environment. Proceedings of the 11th Australian Agronomy Conference, Geelong, Victoria, Australia, 2–6.

GRDC Project ICA00008—Breeding chickpea for drought tolerance and disease resistance

This project aimed to enhance production, productivity and yield stability of chickpea under Mediterranean and similar Australian environments through genetic improvement and agronomic options. Most chickpea cultivars grown by farmers in Mediterranean and Australian environments are susceptible to Ascochyta blight, affected by terminal drought, and are susceptible cold stress during the vegetative and flowering stage.

To overcome these constraints, GRDC has funded a project aimed at developing methodologies, screening tools, and improved germplasm for Ascochyta blight resistance and drought related traits. The newly developed materials and methodologies will be shared with National Agricultural Research Systems (NARS) in West Asia and North Africa (WANA) and pulse breeding programs in Australia.

Identification of new sources of resistance/tolerance for Ascochyta blight, drought and Fusarium wilt is a continuous process, as the pressure from these stresses is continuously evolving. This project delivers improved germplasm for these stresses and other desirable traits, including good plant type suitable for mechanical harvesting, to Pulse Breeding Australia for the benefits of Australian farmers. Resistances to Ascochyta blight, drought, and Fusarium wilt were bred into adapted Australian cultivars and the new derived progenies have been advanced at International Center for Agricultural Research in Dry Areas (ICARDA). These materials will be shared with Australian partners at the advanced stage to screen under Australian conditions for relevant stresses. Selected lines will be either used in crossing programs or for testing in yield trials for direct release as cultivars. Pathway to market is through the release and adoption of improved chickpea varieties.

All these efforts are contributing to widen the genetic base of Australian chickpea, which will bring more plasticity to face any future threats to production. The adoption by farmers of new varieties developed from these materials, with improved drought tolerance and disease resistance, will lead to increased and sustainable chickpea production and thereby contribute significantly to raising the level of the chickpea industry in Australia. [60]

14.5 Other environmental issues

14.5.1 Salinity

Salinity is the presence of dissolved salts in soil or water. It causes iron toxicity in plants and impedes their ability to absorb water (see Figures 22 and 23 for typical salt effects). Salinity, a major abiotic stress, is a major environmental production constraint in many parts of the world. Chickpeas are extremely sensitive to salinity and can have difficulty accessing water and nutrients from saline layers in the soil. This effectively limits water extraction from the subsoil and consequently yields. Salinity impairs vegetative growth in chickpea, but reproductive growth is particularly salt sensitive.

60 GRDC. Project ICA00006. Breeding chickpea for drought tolerance and disease resistance, http://finalreports.grdc.com.au/ICA00006

Figure 22: *Salt effects as seen on a soil of EC 11 ds/m.* [61]

Figure 23: *Pod setting under salinity of a salinity tolerant and salinity sensitive genotype (left). The photograph shows that biomass can be very similar even though pod set can be differentially affected by salinity.* [62] *Typical salt effects on chickpea leaves (right).* [63]

More than one million hectares of broadacre farmland in WA is estimated to be currently affected by dryland salinity (Report Card for the south-west of Western Australia 2013, DAFWA). DAFWA is able to provide the technical information needed to assist landholders and the community to reduce the extent and effect of salinity. Through activities such as groundwater and soil analysis, landholders can confidently assess salinity risks and implement appropriate management responses. [64]

Nut grass (Figure 24) is often a good indicator of increased salt levels.

61 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

62 V Vadez, L Krishnamurthy, PM Gaur, HD Upadhyaya, DA Hoisington, RK Varshney, KH Siddique (2006) Tapping the large genetic variability for salinity tolerance in chickpea. In Proceeding of the Australian Society of Agronomy meeting (10–14 September) http://www.agronomy.org.au

63 Pulse Australia Ltd (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

64 DAFWA. Soil salinity. https://www.agric.wa.gov.au/climate-land-water/soils/soil-constraints/soil-salinity

Figure 24: *Nut grass growing in saline soil.* [65]

All current varieties of chickpea are considered highly sensitive to salinity. Levels of EC >1.5 dS/m will cause a yield reduction in chickpea (Table 6). The growth of chickpea is very sensitive to salinity, with the most susceptible genotypes dying in just 25 mm NaCl and resistant genotypes unlikely to survive 100 mm NaCl in hydroponics; germination is more tolerant with some genotypes tolerating 320 mm NaCl. When growing in a saline medium, Cl-, which is secreted from glandular hairs on leaves, stems and pods, is present in higher concentrations in shoots than Na+. Salinity reduces the amount of water extractable from soil by a chickpea crop and induces osmotic adjustment, which is greater in nodules than in leaves or roots. Chickpea rhizobia show a higher 'free-living' salt resistance than chickpea plants, and salinity can cause large reductions in nodulation, nodule size and N_2-fixation capacity. [66]

Table 6: *Crop tolerances to salinity (EC, mmhos/cm = dS/m = mS/cm).*

Crop	Expected yield reduction (%).				
	0	10	25	50	100
Chickpea	1.3	2.0	3.1	4.9	8.0
Barley	8.0	10.0	13.0	18.0	56.0

Source: adapted from Mass and Hoffman (1977) and Abrol (1973)

A 2016 study concluded that salt sensitivity in chickpeas is determined by Na(+) toxicity. [67] Another study suggested that Na+ accumulation in leaves is associated with delayed flowering, and that it is this plays a role in the lower reproductive success of the sensitive lines. The delay is longer in sensitive genotypes than in tolerant ones. Filled pod and seed numbers, but not seed size, have been associated with reduced seed yield in saline conditions. [68]

65 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

66 TJ Flowers, PM Gaur, CL Gowda, L Krishnamurthy, S Samineni, KH Siddique, TD Colmer (2010) Salt sensitivity in chickpea. Plant, cell & environment, 33(4), 490–509.

67 HA Khan, KHM Siddique, TD Colmer (2016) Salt sensitivity in chickpea is determined by sodium toxicity. Planta, 244 (3), 1–15, https://www.ncbi.nlm.nih.gov/pubmed/27114264

68 R Pushpavalli, J Quealy, TD Colmer, NC Turner, KHM Siddique, MV Rao, V Vadez (2016) Salt stress delayed flowering and reduced reproductive success of chickpea (*Cicer arietinum* L.), a response associated with Na+ accumulation in leaves. Journal of Agronomy and Crop Science, 202 (2), 125–138, http://onlinelibrary.wiley.com/doi/10.1111/jac.12128/abstract

It has also been found that salt stress reduces photosynthesis, decreases tissue sugars by 22–47%, and severely impairs vegetative and reproductive growth. [69]

Salt stress is thought to reduce germination either by making less water available for imbibition or by altering enzymatic activity, growth-regulator balance or protein metabolism in germinating seeds. One study has found that pre-soaking seeds for 24 hours in normal ground or tap water (0.8 dS m-1) increased germination by 27% compared to direct sowing. Sowing at depth of 4 cm also increased seedling growth under saline soils compared with sowing at 2 cm and 6 cm.

Altered growth-hormone balance during germination is another factor resulting in poor germination and seedling growth under salt stress. The application of growth regulators such as gibberellic acid and kinetin have been found to increase germination (32%), root (32%) and shoot (153%) dry mass of seedlings stressed by salt. [70]

IN FOCUS

Effects of salt stress on growth, nodulation, and nitrogen and carbon fixation of ten genetically diverse lines of chickpea

Over two dry seasons, 10 genetically diverse chickpea lines were compared for salt tolerance in terms of growth, nodulation, moisture content, and nodule nitrogen and carbon fixation. Chickpea lines were raised in an open-air chamber in soil supplied with 0, 50, 75, and 100 mM NaCl. The shoot, root, and the single-plant weight declined with increasing level of salt. An almost identical pattern of salt response was observed for nodule number, weight per nodule, nitrogen, and carbon fixation among the chickpea lines. No distinct relationship was found among root/shoot ratio, plant moisture content, and salt tolerance response of the chickpea. However, nodulation capacity (number and mass) under salt stress was related to salt tolerance response of chickpea lines. This trait could be used for improvement of salt tolerance of this legume species in order to increase its productivity and stability in saline soils. The research demonstrates that nodule number and not nodule mass is the trait that can be used as a useful marker in studying salt stress in chickpea. [71]

MORE INFORMATION

DAFWA, Dryland salinity in WA – an introduction.

14.5.2 Soil chloride levels

Soil chloride levels >600 mg/kg have been found to reduce root growth in crops such as chickpea, lentil and linseed. Soil analysis should be conducted to identify levels ofchloride and at what depth it changes. Thresholds for chloride concentration in soil and yield reductions differ between crops (Tables 7 and 8).

69 HA Khan, KHM Siddique, TD Colmer (2016) Vegetative and reproductive growth of salt-stressed chickpea are carbon-limited: sucrose infusion at the reproductive stage improves salt tolerance. Journal of Experimental Botany. Published online May 2016. DOI 10.1093/jxb/erw177, http://jxb.oxfordjournals.org/content/early/2016/04/29/jxb.erw177.full

70 S Samineni (2010) Physiology, Genetics and QTL Mapping of Salt Tolerance in Chickpea. Thesis. University of Western Australia.

71 B Singh, BK Singh, J Kumar, SS Yadav, K Usha (2005) Effects of salt stress on growth, nodulation, and nitrogen and carbon fixation of ten genetically diverse lines of chickpea (Cicer arietinum L.). Crop and Pasture Science, 56(5), 491–495.

Table 7: *Thresholds for chloride concentration in soil (mg/kg).*

Crop	10% Yield reduction	50% Yield reduction
Chickpeas	600	1,000
Bread wheat	700	1,500
Durum wheat	600	1,200
Barley	800	1,500
Canola	1200	1,800

Source: QLD Natural Resources and Water Bulletin

Table 8: *Soil constraint ratings for concentration of chloride (Cl) and Sodium (Na).*

Low	Medium	High
Surface soil (top 10 cm)		
<300 mg Cl/kg	300–600 mg Cl/kg	>600 mg Cl/kg
<200 mg Na/kg	200–500 mg Na/kg	>500 mg Na/kg
Subsoil (10 cm to 1m)		
<600 mg Cl/kg	600–1,200 mg Cl/kg	>1200 mg Cl/kg
<500 mg Na/kg	500–1,000 mg Na/kg	>1000 mg Na/kg

Source: QLD Natural Resources and Water Bulletin

Agronomic practices and crop choice

Agronomic practices and crop choices may have to vary for differing levels of soil salinity or sodicity constraints. Pulses such as chickpeas can be grown only where there are low salinity constraints.

Low constraints of Na and Cl (<600 mg Cl/kg, <500 mg Na/kg in top 1 m soil depth):

- Cereal–legume rotations are possible.
- Canola can be grown.
- Opportunity cropping to utilise available soil water can be tried.

Medium constraints of Na and Cl (600–1,200 mg Cl/kg, 500–1,000 mg Na/kg in top 1 m soil depth): tolerant crops should be grown (wheat, barley, canola):

- Consider tolerant crop varieties.
- The more tolerant of the pulses (vetch, faba bean, possibly lupin and field pea) will likely suffer yield penalties if grown.
- Match inputs to realistic yields.
- Cereal diseases must be managed.
- Avoid growing salt-susceptible pulses (including chickpea and lentil), or durum wheat.
- Opportunity cropping to utilise available soil water can be tried, but options may be more limited.

High constraints of Na and Cl (>1,200 mg Cl/kg, >1,000 mg Na/kg in top 1 m soil depth):

- Avoid growing crops or grow tolerant cereals.
- Match inputs to realistic yields.
- Consider alternative land use to cropping (e.g. saline-tolerant forages, pastures).

14.5.3 Soil pH

Chickpea crops are best suited to well-drained loam and clay loam soils that are neutral to alkaline (pH 6.0 to 9.0). [72]

Acidic soils

Acid soils can significantly reduce production and profitability before paddock symptoms are noticed. Danger levels for crops are when soil pH is less than 5.5 (in $CaCl_2$) or 6.3 (in water). Monitor changes in soil pH by regular soil testing. If severe acidity is allowed to develop, then irreversible soil damage can occur. Prevention is better than cure, so apply lime regularly in vulnerable soils. The most effective liming sources have a high neutralising value and have a high proportion of material with particle size smaller than 0.25 mm. More lime is required to raise pH in clays than in sands. Liming can induce manganese deficiency where soil manganese levels are marginal. Low soil pH often leads to poor or ineffective nodulation in pulses because acid soil conditions affect rhizobial initial numbers and multiplication. Field peas, faba beans, lentil and chickpea are vulnerable, as are vetches. Lupins are an exception because their rhizobia (Group G) are acid-tolerant. Granular inoculums seem to provide greater protection to rhizobia in acid soil conditions.

Between pH Ca 5.5 and pHCa8 is the ideal pH range for plants. Soil pH targets, as set by DAFWA and industry, are 5.5 in the topsoil, 0–10 cm, and over 4.8 in the subsurface soil, 10 cm and below. At pH ca of 4.8, or lower, levels of aluminium in the soil increase to toxic levels. Free aluminium has a large impact on crop yield. It reduces root growth in turn reducing the depth of soil the plant has access to.

In terms of lime movement through the soil, a pH level of 5.5 is required in the top 0–10 cm of soil before lime can influence any soil below this level. Lime applied to the surface will be worked in with the traffic of the seeding implement. This creates a layer where the pH is ameliorated to the depth of the seeding point but no further. Lime must be in contact with the soil of low pH in order to react. This layering effect has an impact on yield potential of rotation crops and pastures. An ameliorated surface, above pHca5.5, and subsurface with pH ca below 4.8 reduces the yield potential of rotation crops and the efficacy of N fixation. In spite of a lime application the subsurface pH remains unchanged until the lime is able to leach through the profile.

There is potential for incorrect decisions to be made without full knowledge of the soil pH to depth. This is particularly true when the crop is susceptible to low pH or aluminium toxicity, as are break crops like chickpea. Poor yields of these rotation crops may be the result of low pH at depth, in spite of good pH at the surface. A surface soil pH ca of 5.5, suitable for pulse crops, may conceal low pH in the subsurface unsuitable for pulse crops.

Soil pH in WA

A high proportion of paddocks (39%) sampled in the Profitable Crop and Pasture Sequences project (AKA Focus Paddocks) have subsurface pH below minimum target of pH Ca 4.8. The project also found 37% of sampled paddocks have pH Ca in the surface greater than 5.5 (Figure 25). Of these paddocks, 40% have pH ca of less than 4.8 at 10–30 cm. This has negative implications for legume break crops field pea and chickpea, and also legume pastures sown into these paddocks. [73]

72 Agriculture Victoria.(2016). Growing Chickpea. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-chickpea

73 W Parker DAFWA (2014) Crop Updates—Break crops being sown onto unsuitable soils, unsuspectingly.

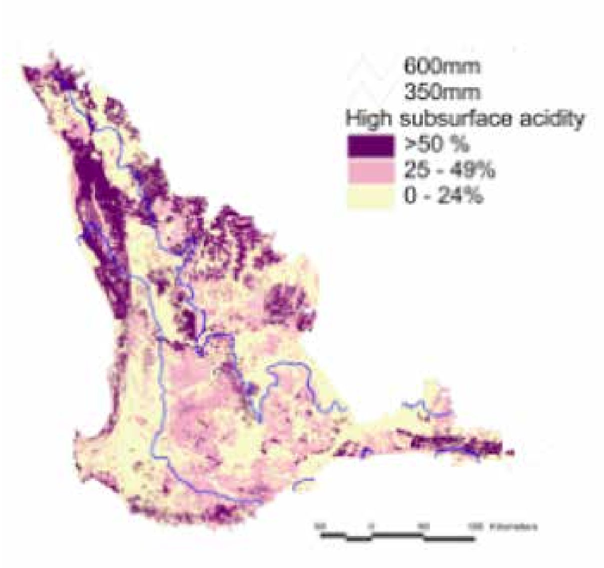

Figure 25: *The distribution of soils that are currently acid (pH<4.5 at 20 cm) or at high risk of subsurface acidity (within 10 years) determined using DAFWA's map unit database, accessed in May 2006.* [74]

Source: Davies et al. (2006)

Alkaline soils

In alkaline soils (Figure 26), the abundance of carbonates and bicarbonates can reduce crop growth and induce nutrient deficiencies. Presence of free lime has a major impact on lupin growth, inducing iron and manganese deficiency, which cannot be corrected by foliar sprays of those nutrients.

74 S Davies, C Gazey, B Bowden, D Van Gool, D Gartner, T Liaghati, B Gilkes (2006) Acidification of Western Australia's agricultural soils and their management. In Groundbreaking Stuff. Proceedings of the 13th Australian Agronomy Conference. Perth, Western Australia (N Turner & T Acuna, Eds.) p.[on line]. The Regional Institute Ltd, http://www.regional.org.au/au/asa/2006/concurrent/soil/4555_daviess.htm.

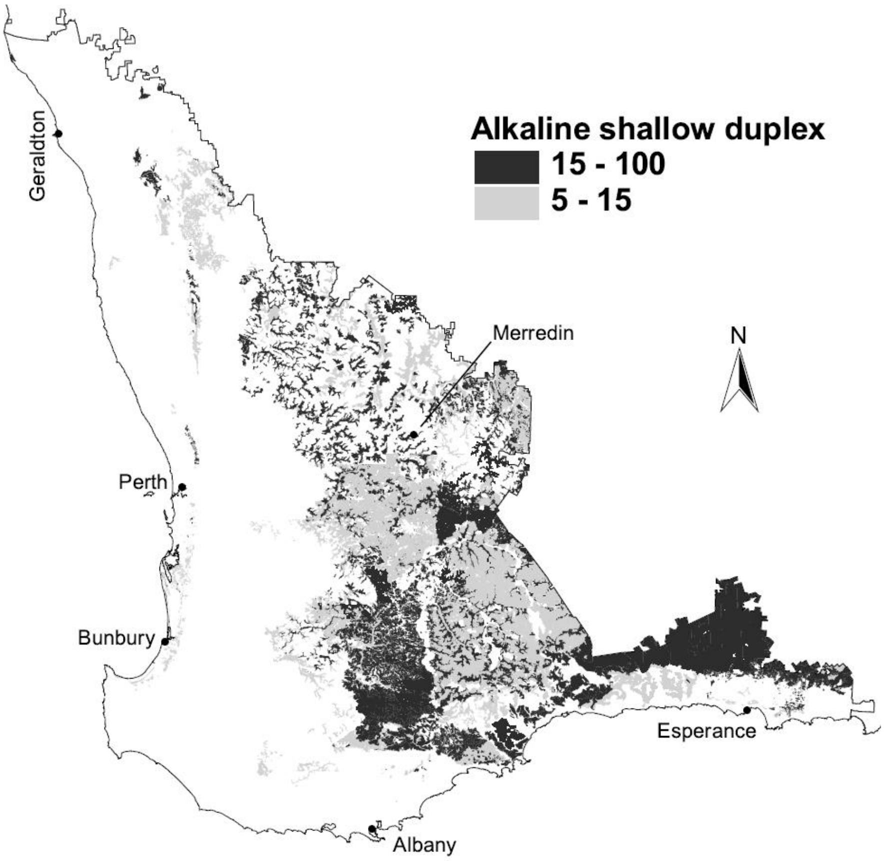

Figure 26: *Distribution of Alkaline shallow duplex soils in WA.*

Source: DAFWA

Managing soil acidity

Key points:

- Soil acidity across the south-west agricultural region of Western Australia is a major production constraint and is getting worse.
- Growers are applying more lime per hectare than in the past but, in many cases, much more lime is needed to recover the soil profile.
- Liming to remove soil acidity as a production constraint can also bring the benefits of increasing yields, maximising crop and pasture choice, and helping to protect the soil resource.

Soil acidification is an ongoing issue

Soil acidification is an ongoing and unavoidable result of productive agriculture. The main practices that cause soil acidification include removing harvested products and leaching of nitrate from soil. Because soil acidification is an ongoing result of farming, management also needs to be ongoing.

Lime use is increasing

Farmers in WA are increasing their use of lime and appropriate soil sampling to identify and prioritise lime application. For example, a survey was conducted of nearly 400 grain growers from across the WA wheat belt who indicated that the most common rates of application of lime would increase from 1–1.5 t/ha to 1.5–2 t/ha. Farmers also indicated that they intended to increase their testing of soil acidity in the subsurface layers.

Farmers in WA are also using more targeted applications of lime. Over 2010 to 2012, 75% of farmers applied lime at a single rate across paddocks. This method results in most soils receiving either too little or too much lime and not enough lime use overall. In the future, 50% of farmers intend to lime according to management areas or 'patch out' lime based on soil sampling results.

Soil acidification is still increasing

Despite higher applications of lime, the evidence clearly shows that soil pH in many areas of the south-west agricultural region is continuing to decline (Figure 27). Currently, more than 70% of soil samples from the 0–10 cm layer have pH in $CaCl_2$ below the minimum appropriate level of 5.5. In the 10–20 cm and 20–30 cm layers of soil, almost 50% of soil samples have pHCa below the minimum appropriate level of 4.8.

Soil acidity continues to be a major constraint to yield in Western Australia. Soil acidity costs WA agriculture about $500 million per annum in lost productivity. Without appropriate management, soil acidity will continue to prevent farmers from achieving their rain limited yield potential.

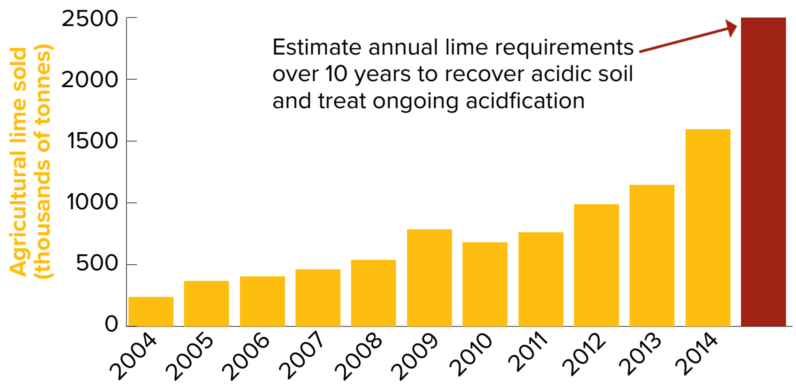

Figure 27: *Agricultural lime sales show that although lime use is increasing, it is only 60% of the estimated annual requirement for the next 10 years*

Source: Lime WA Inc.

More lime is needed

To manage soil acidification in WA, more lime must be applied to agricultural soils. The most effective method is to apply the right rate of lime in the right place at the right time. This will use resources most effectively and provide the best returns on investment.

The importance of soil testing

Soil testing has a vital role in the management of soil acidity. It is important that decisions on where and when to apply lime and how much lime to apply are based on objective measures of soil acidity. While it is possible to estimate maintenance liming rates based on farm inputs and outputs, the most direct method—and the only way to measure existing acidity—is to regularly test the surface and subsurface soil layers.

Yield increases from liming

Liming can increase grain yield when soil pH is below recommended targets and when soil pH is one of the factors constraining yield. DAFWA and the CSIRO investigated how liming affected yield in 69 lime trials from across the WA wheat belt. On average, applying lime increased yield by 0.2 t/ha, or 10%. This result is similar to findings in most other trials around Australia. However, the yield increases from liming may be even higher than this. When trials have included ripping or tillage,

MORE INFORMATION

Soil acidity and liming.

increases in yield were even greater. Also, it takes a few years for lime to react with the soil and increase the soil pH. If yield was calculated starting from the third harvest after lime was applied, the average yield increase was 0.25 t/ha, or 16%. Yield and yield gains from liming will depend on the relationship between paddock yield and yield potential. If the paddock yield is low relative to the yield potential, there is likely to be additional constraints present and there may be little gain from liming. Also, if the paddock yield is already close to potential pH is not likely to be a constraint and there may also be little immediate gain from liming. However, maintenance liming will be required to counter ongoing acidification and maintain the productivity of the paddock. [75]

14.5.4 Sodicity

Chickpea is classified among the most sensitive of all field crops to sodic soil conditions.

Soils high in sodium are structurally unstable, with clay particles dispersing when wet. This subsequently blocks soil pores, reduces water infiltration and aeration, and retards root growth. On drying, a sodic soil becomes dense and forms a hard surface crust up to 10 mm thick. This can also restrict seedling emergence. Sodic soils occupy almost one-third of the land area of Australia.

Some indicators of surface sodicity include:

- soils prone to crusting and sealing up
- ongoing problems with poor plant establishment
- presence of scalded areas in adjoining pasture

Exchangeable sodium percentage is the measure for sodicity:

- ESP less than 3: non-sodic soils
- ESP 3–14: sodic soil
- ESP greater than 15: strongly sodic

Sodicity has serious impacts on farm production, as well as significant off-site consequences such as:

- surface crusting
- reduced seedling emergence
- reduced soil aeration
- increased risk of run-off and erosion
- less groundcover and organic matter
- less microbial activity

Sodic soils are known as dispersive clays and reduce seedling emergence (Figure 28).

Sodic soils are can lead to tunnel erosion—they turn to slurry when wet, and channels are easily created through them by moving water. [76]

75 C Gazey, J Carson. Managing soil acidity–Western Australia Fact Sheet. The National Soil Quality Monitoring Program, http://www.soilquality.org.au/factsheets/managing-soil-acidity-western-australia

76 Corangamite CMA (2013) How do I manage the impact of sodic soils? Corangamite CMA, http://www.ccmaknowledgebase.vic.gov.au/brown_book/04_Sodic.htm

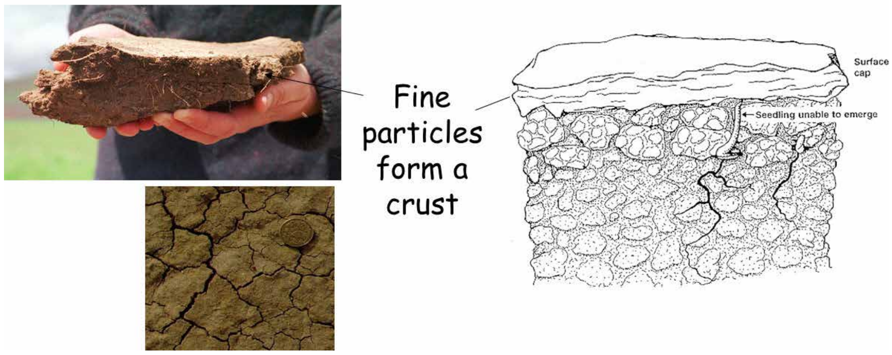

Figure 28: *The impact of sodic soils on seedling emergence: surface crusting and dispersive clay limit emergence.*

Source: Corangamite CMA

Soils that are sodic in the topsoil have the greatest impact on crop performance (see Figure 29 for effect of ESP on chickpea yield). Sodic layers deeper in the soil profile are not as great a concern but can still affect yields by restricting root development and water extraction from depth. The net effect of severely restricted root growth in chickpeas is usually the early onset of drought stress.

It is unlikely that soil sodic layers deeper than 90 cm will have significant impact on chickpea yields.

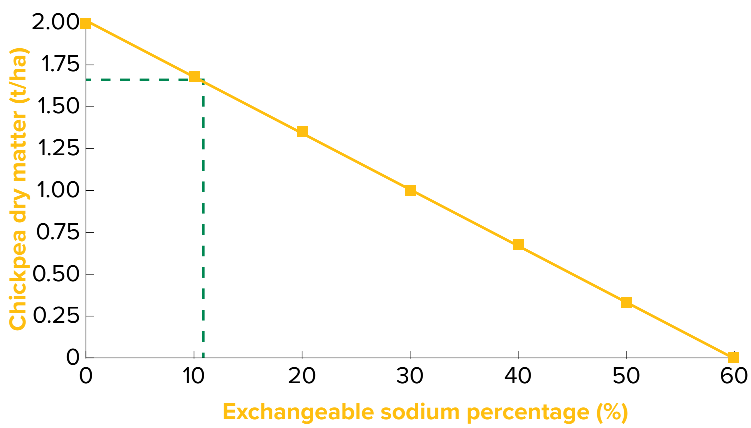

Figure 29: *Impact of sodicity on chickpea dry matter production.* [77]

Source: Pulse Australia Ltd

Sodic soils in WA

Sodic soils are common throughout WA, particularly in the south-west agricultural area where they occur mainly as duplex or gradational profiles. Soils with sodic properties are dominant in 26% of the state; saline-sodic sediments and soils in intermittent streams, lakes and estuarine plains occupy a further 5%. Sodic soils are moderately common throughout the southern and western portion of the rangeland areas (38% of the state). The south-west coastal sands and the desert and rangeland soils to the north and east of the state are rarely sodic. Efficient management of sodic soils in these areas must rely on the prevention of degradation and the use of biological and physical means to maintain adequate soil physical properties. Effective restoration of degraded sodic soils, however, often does require application of inorganic amendments in combination with tillage to initiate structural recovery. Sodicity is currently not considered to be a problem at any of the three main irrigation

77 Pulse Australia Ltd (2013) Northern chickpea best management practices training course manual–2013.

areas in WA, but all have sodic soil within their potentially irrigable lands, which may limit their future expansion. [78]

Managing sodic soils

- Growers need to correctly identify the problem first and ensure that the soils are in fact sodic.
- Sodic soils can be directly treated through the application of gypsum (particularly on the surface), which serves to replace the excess sodium in the soil with calcium.
- In southern Victoria, typical application rates of gypsum are around 2.5 t/ha and applied every 3–5 years.
- The application of lime to sodic soils acts in a similar manner to gypsum, but is much slower acting and less effective.
- Although the application of gypsum can effectively counter sodicity in the short run, longer-term management strategies need to be in place to increase, and then maintain, organic matter in soils. Increased organic matter can improve hard-setting soils, and it can also enhance the effect of gypsum.
- Sodicity can also be reduced by maintaining adequate vegetation cover, leaf litter or stubble on the soil surface.
- Trials in the high-rainfall zone of southern Victoria have shown that the amelioration of dense sodic subsoil using organic amendments can increase wheat yield more than using gypsum. [79]

78 HR Cochrane, G Scholz, AME Vanvreswyk (1994) Sodic soils in western Australia. Soil Research, 32(3), 359–388.

79 P Sale, J Gill, R Peries, C Tang (2008) Amelioration of dense sodic subsoil using organic amendments increases wheat yield more than using gypsum in a high rainfall zone of southern Australia. La Trobe University, Bundoora, Victoria.