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GRAINS RESEARCH & DEVELOPMENT CORPORATION

CHICKPEA

SECTION 1

PLANNING AND PADDOCK PREPARATION

PADDOCK SELECTION | PADDOCK ROTATION AND HISTORY | FALLOW WEED CONTROL | FALLOW CHEMICAL PLANT-BACK EFFECTS | SEEDBED REQUIREMENTS | SOIL MOISTURE | YIELD AND TARGETS | DISEASE STATUS OF PADDOCK | NEMATODE STATUS OF PADDOCK | TESTING SOIL FOR DISEASE AND NEMATODES | INSECT STATUS OF PADDOCK

Planning/Paddock preparation

Key messages

- To reduce disease risk, chickpea crops should be separated from the previous year's chickpea crop by at least 500 m and up to 1 km in areas where old stubble is prone to movement; i.e. downslope and on flood plains.
- Avoid paddocks with high weed burdens, as chickpeas provide poor competition for weeds.
- Chickpeas are not as well suited to low rainfall areas (less than 350 mm) (Figure 1). Kabuli types are less tolerant than desi types to dry conditions, as they require more moisture to achieve a satisfactory grain size and yield. Desi types require above 350 mm annual rainfall and kabuli types need more than 400 mm.
- Chickpea is an advantageous crop rotation because of its nitrogen-fixing ability, however, it can be susceptible to nematodes.
- Consider herbicide residual and plant-back effects before sowing.
- Prior to sowing it is important to consider disease, nematode and pest management by knowing paddock history and testing soils for these issues.

Figure 1: *Ideal conditions for chickpea growth.*

Source: Pulse Australia

WATCH: Growing profitable pulses

1.1 Paddock selection

Key points

- Well-drained soils with a pH above 5.5 in calcium chloride ($CaCl_2$), heavy deep clays, heavy loam, sandy loam and Salmon Gum soils. Avoid soils with a pH below 5.5 ($CaCl_2$), saline soils, high boron soils and Wodjil soils. Chickpea has poor tolerance of low pH where aluminium toxicity can be a problem.
- Check soil tests to determine if the soil type is suitable for chickpea production; i.e. pH 5.2–8.0, loams to self-mulching clays, sufficient stored soil moisture, absence of herbicide residues and absence of constraints such as sodicity, salinity/chloride, high bulk density and potential for waterlogging.
- A soil structure and slope which allows good drainage—avoid shallow soils.
- Little or no risk of sulfonylurea carry-over.
- A low broadleaf weed burden.
- Remove rocks from paddocks. The paddock surface needs to be left relatively even and flat after sowing for easy harvest.
- To minimise the risk of diseases, do not grow chickpeas more often than one year in four in the same paddock and at least 500 m from last season's chickpea stubble. [1]
- Chickpea crops should be separated from previous year's crop by at least 500 m and up to 1 km in areas where old stubble is prone to movement; i.e. downslope and on flood plains. This helps to reduce the spread of ascochyta blight, a foliar/stubble-borne disease.

Aim to direct-drill chickpeas into standing cereal stubble. Crops reliably yield 10% higher when established this way. Uniformity of soil type, paddock topography, and surface condition of the paddock are all important criteria in assessing whether country is suitable for chickpea production. Harvest losses are much higher in rough or uneven paddocks, particularly in dry seasons when crop height is reduced. Sticks or rocks, eroded gullies or gilgais ('melon' or 'crab' holes) will prevent headers operating at low cutting height. This is particularly important when using headers with wide fronts. Small variations in paddock topography can lead to big variations in cutting height across a wide front and a subsequent increase in harvest losses.

Moisture supply can significantly affect crop maturity. Changes in soil type and moisture-holding capacity across a paddock can lead to uneven crop maturation, delayed harvesting and increased risk of weather damage or high harvest losses.

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

Paddocks that have even soil types are relatively easier to manage, and are preferred for chickpeas. [2]

Selecting a paddock with minimal variation in soil type will often help to provide even maturity and ripening of the crop. This will enable harvesting at the earliest possible time, increase quality, and minimise harvest losses. The overall result is usually a more profitable crop.

1.1.1 Avoid deep gilgai or heavily contoured country

Contours and undulating country ('melon holes' or 'crab holes') present two problems:

- Uneven crop maturity due to variation in soil water supply. Melon-holes usually store more water than the mounds, and the crop in wetter areas will often continue to flower and pod when the rest of the crop is already drying down. Similarly, contour banks retain more moisture after rain, and prolong crop maturity relative to the rest of the crop late in the crop.
- High harvest losses and increased risk of dirt contamination in the header sample. Many dryland chickpea crops require the header front to be set close to ground level, and even small variations in paddock topography can lead to large variations in cutting height across the header front, and a significant increase in harvest losses.

Contamination of the harvested sample with dirt and clods is difficult to avoid in undulating, gilgai country, and can cause a significant increase in grading losses and costs.

Foreign material must not exceed 3% by weight, of which no more than 0.3% must be unmillable material (soil, stones and non-vegetable matter). If a farmer delivers chickpeas that do not meet this export standard, they will need to be graded at a cost of $15–25/t.

1.1.2 Soil

Desi chickpea is well suited to many of the calcareous red-brown earths, duplex soils, and shallow red earth soils that constitute about 60% of the agricultural land in the low rainfall regions of south-western Australia. [3]

Prior to planting, review soil tests and records, paying particular attention to the following soil characteristics:

- soil type: loams to self-mulching clays
- pH 5.2–8.0
- saline soils: ECe >1.5 ds/m will cause a yield reduction
- sodicity: >1.0 surface or >5.0 in subsoil can limit yield
- high boron and soil chloride levels >600 mg/kg in subsoil layers severely limit root growth, depth and water extraction from the soil
- potential waterlogging problems—avoid compacted soils or areas where free water does not drain away and/or remains saturated. Spring sowing may be an option in higher rainfall areas [4]
- amount of stored soil moisture and received rainfall
- note potential impacts of herbicide residues [5]

For more information on causes and management of waterlogging, salinity, sodicity and chloride issues, see Section 14: Environmental issues.

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2 Pulse Australia. Chickpea production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

3 Jettner, R. J., Loss, S. P., Siddique, K. H. M., & French, R. J. (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), 1017-1026.

4 Pulse Australia. Southern Pulse Bulletin PA 2010 #05 – Chickpea checklist for southern growers. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-checklist-south.pdf

5 G Cumming (2014) Chickpea varieties selecting horses for courses. GRDC Update Papers 5 March 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Chickpea-varieties-selecting-horses-for-courses

Chickpeas will not grow in light acid soils and areas prone to waterlogging should be avoided. Chickpea crops must be harvested close to the ground so stony paddocks or fields with uneven soil surface (e.g. gilgai) should be avoided.

Chickpea are susceptible to hostile subsoils, with boron toxicity, sodicity and salinity causing patchiness in affected paddocks. Chickpea will not tolerate soils with any exchangeable aluminium present. Tolerance to sodicity in the root zone (to 90 cm) is less than 1% exchangeable sodium (ESP) on the surface and less than 5% ESP in the subsoil. [6]

WATCH: Novel approaches to tackling soil acidity in the west.

IN FOCUS

Adaptation and seed yield of cool-season grain legumes in Mediterranean environments of south-western Australia.

A range of cool-season grain legume species have shown considerable potential for soils unsuitable for the production of narrow-leafed lupin (*Lupinus angustifolius* L.) at limited sites in the Mediterranean-type environments of south-western Australia. In one study the adaptation of these grain legume species was compared by measuring crop phenology, growth, and yield in field experiments at 36 sites over three seasons, with the aim of identifying species with suitable adaptation and seed yield for specific environments. Soil pH and clay content and rainfall were the environmental factors identified as the most important in determining seed yields. Soil pH and clay content appeared to be especially important in the adaptation of kabuli chickpea, performing best in soils with pH >6.0 and clay contents >15%. [7]

6 Pulse Australia. Chickpea production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

7 SiddiqueABD, K. H. M., LossAB, S. P., ReganA, K. L., & JettnerC, R. L. (1999). Adaptation and seed yield of cool season grain legumes in Mediterranean environments of south-western Australia. Aust. J. Agric. Res, 50(375), 87.

Subsoil

Chickpeas are suited to soils with a surface pH($CaCl_2$) of greater than 5.0, particularly if pH rises to above 5.5 within 10-15 cm of the surface. [8]

Subsurface pH is of importance to the break crop in the rotation. Knowing the pH at depth is vital for an effective break crop, particularly if the surface soil is testing at or above the target of pH 5.5. Subsurface soil pH results in WA have not been favourable and many growers are deciding the best way to invest is to repair it. This may be through applying more lime than initially planned and mechanical incorporation of the lime. Recent surface-applied lime has yet to impact on the subsurface soils without mechanical incorporation in many soil types.

In a sample of 184 paddocks across the WA growing region, 38% of all paddocks had satisfactory surface pH of 5.5 or above, and 40% of these had subsurface pH values below target (Less than pH 4.8.). Overall, 23% of the 184 paddocks had satisfactory surface and sub surface soil for growing chickpeas.

The break crops chickpea, field pea and canola are all sensitive to acidity. These crops will not be productive in spite of a hospitable surface soil (pH greater than 5), as the acid subsurface will prevent root growth and nutrient adsorption. Testing the subsurface soil pH will help make better decisions of crop type and variety for rotation. [9]

WATCH: Over the Fence West: Spading pays off for Moora grower.

1.1.3 Soil pH

Key points:

- Soil pH is a measure of the concentration of hydrogen ions in the soil solution.
- Low pH values (<5.5) indicate acidic soils and high pH values (>8.0) indicate alkaline soils.
- Soil pH between 5.5 and 8 is not usually a constraint to crop or pasture production.
- In South Australia, more than 60% of agricultural soils are alkaline.
- Outside of the optimal soil pH range, microelement toxicity damages crops.

Hydrogen ion concentration in the soil is called pH and is influenced by chemical reactions between soil components and water. Soil pH is affected by the varied combinations of positively charged ions (sodium, potassium, magnesium, calcium, aluminum, manganese, and iron) and negatively charged ions (sulfate, chloride,

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

9 Parker W. DAFWA (2013). Profitable crop and pasture sequencing 2013 trial report. https://www.agric.wa.gov.au/grains-research-development/profitable-crop-and-pasture-sequencing-2013-trial-report?page=0%2C0

bicarbonate, and carbonate). Soil pH directly affects the concentration of major nutrients and the forms of microelements available for plant uptake and can result in deficiencies or toxicities (Figure 2).

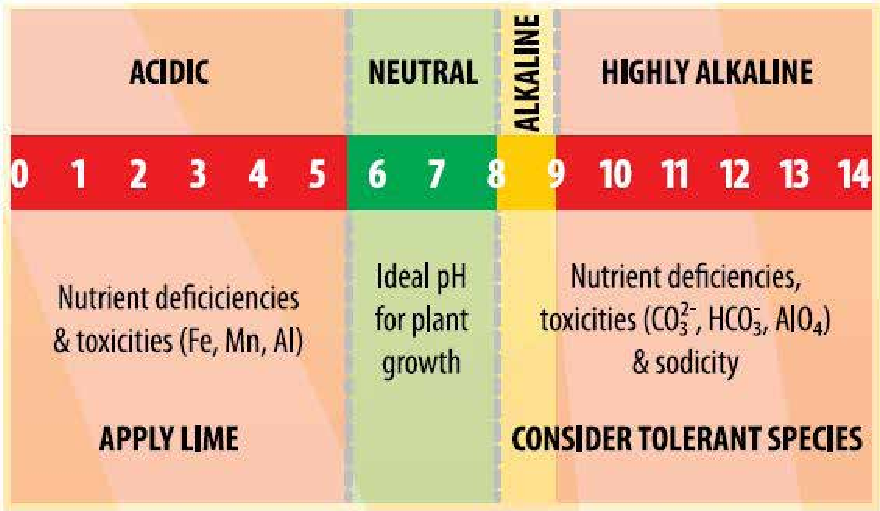

Figure 2: *Classification of soils on the basis of pH (1:5 soil:water), the implications for plant growth and some management options.*

Source: Soilquality.org

MORE INFORMATION

Soil acidity Western Australia

Soil acidity is a major constraint to farming in Western Australia. Extensive surveys of soil pH profiles across the south-west show that more than 70% of surface soils and almost half of subsurface soils are below appropriate pH levels. The majority of growers now place soil acidity in their top three management priorities. Managing soil acidity is both achievable and profitable.

Managing soil pH

Acid soils

Acid soils can be economically managed by the addition of agricultural lime, usually crushed limestone. Sufficient lime should be added to raise the pH to above 5.5. The amount of lime required to ameliorate acid soils will vary, mainly depending on the quality of the lime, soil type, and how acidic the soil has become.

Soils prone to becoming acidic will need liming every few years. Seek advice on an appropriate liming regime from your local agricultural advisor.

Alkaline soils

MORE INFORMATION

DAFWA - Soil pH

Treating alkaline soils by the addition of acidifying agents is not generally a feasible option due to the large buffering capacity of soils and uneconomic amounts of acidifying agent (e.g. sulfuric acid, elemental sulfur, or pyrites) required.

Gypsum will reduce sodicity and this can reduce alkaline pH to some extent. Growing legumes in crop rotation may help in sustaining any pH reduction.

In high pH soils, using alkalinity tolerant varieties of crops and pasture can reduce the impact of high pH. [10]

1.1.4 Rainfall

Chickpeas are not well suited to the lower rainfall, hotter areas, although the plants will set seed under warmer conditions where other pulse crops are likely to fail. Cool wet conditions are more likely to stimulate foliar diseases and these can adversely affect seed set and yield. Desi varieties should only be grown in areas where the annual rainfall is greater than 350 mm. Sowing is best carried out from early May

10 Soiquality.org. Soil pH- South Australia. http://www.soilquality.org.au/factsheets/soil-ph-south-austral

to early June with early sowing recommended for the lower rainfall areas. Kabuli varieties are later maturing and should only be grown in areas where the annual rainfall is over 450 mm. As a higher value crop, kabuli types are often grown on fallow where extra moisture can mean larger seed. [11] When grain prices are high, growing chickpeas on fallow as a cash crop rather than a break crop could be considered.

1.1.5 Physical constraints

Physical constraints decrease oxygen and water movement in soils. Compacted soils and those with high physical strength (bulk density >1.5 g/cm3) impede root growth. Subsoil compaction can be caused by heavy traffic or tillage on wet soils. Compacted layers may be visible, measured by high penetration resistance (> 2 MPa), or indicated by distorted root growth. Deep ripping of soils and use of controlled traffic can help to overcome compaction, but in some soils, amelioration with organic matter, gypsum or lime, for example, may be required as well. Chickpeas are particularly prone to hard pans and compacted soils, and suffer more from waterlogging if compaction layers exist.

WATCH: De-compacting and stabilising compacted soils in WA.

See Section 14: Environmental issues for more information on waterlogging.

1.1.6 Nutrient constraints

Crop management can affect nutrient deficiencies. Iron deficiency in pulses is more likely to occur in wheel tracks and compacted areas. Manganese deficiency is more likely in light, fluffy soil.

In pulses, cobalt and molybdenum are required for nodulation and N fixation, so deficiency of these trace elements can lead to poor nodulation. In higher pH soils, Zinc deficiency is also possible. Ensure good Zinc supply in granular fertiliser or by foliar spray.

1.1.7 Biological constraints

Problems can occur when there is a lack of beneficial organisms such as earthworms and *Arbuscular mycorrhizae* fungi (AMF) in soils. Their build-up can be encouraged by use of stubble retention and direct drilling or no tillage as well as appropriate crop rotations.

11 Pulse Australia. Chickpea production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

1.1.8 Problematic paddocks

Stones and sticks are a concern in poorly or recently cleared country. Harvest losses increase dramatically if the header front needs to be raised to avoid serious mechanical damage to the header. Small stones and wood fragments can also contaminate the seed sample and downgrade quality.

Cloddy or badly ridged paddocks are likely to cause contamination of the chickpea sample during harvest. Level the soil surface as much as possible, either during ground preparation or at sowing. A land-roller can be helpful after sowing, in cultivated situations, to level the soil surface and push clods of soil and small stones back down to level with the surface.

1.1.9 Stubble retention

Chickpeas fit well into stubble retention systems with no tillage, and serve their wider role in crop rotations and farming systems. Retention of adequate plant residues on the surface is important to protect the soil from erosion both during growth and after harvest. This will not affect chickpea germination or growth, and can improve establishment on hard-setting, surface-crusting soils. Sowing into cereal stubble reduces soil moisture losses from evaporation. [12]

Chickpeas established by direct drilling into standing cereal stubble reliably yield 10% higher than when using other planting techniques (Figure 3). [13]

Figure 3: *Better chickpea yields are achieved by sowing into cereal stubble.*

Photo: Gordon Cumming, Pulse Breeding Australia

There are advantages and disadvantage to stubble retention, with high stubble loads potentially causing problems for growers in the following year (Table 1).

12 Pulses Australia. Chickpea Production: Southern and Western region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

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

Table 1: *Advantages and disadvantages in retaining stubble.*

Advantages of stubble retention	Potential disadvantages of stubble retention
Retained stubble provides excellent ground cover (>2.5 t/ha), thus reducing wind and water erosion;	Seeder blockages impact on plant establishment;
increases rainfall infiltration;	Stubble provides ideal habitat for pests to survive;
reduces moisture evaporation (>4.5 t/ha);	physically intercepts herbicides;
eliminates the need to burn, bale or incorporate; and	increases frost risk;
recycles nutrients back into the soil.	carries over diseases; and
	increases potential for nitrogen tie-up.

Based on information from the GRDC

WATCH: Stubble Management.

WATCH: GCTV15: Stubble height Pt. 1. and Stubble height Pt. 2.

WATCH: GCTV4: Burning for stubble retention.

Stubble and its impact on temperature in chickpea crops

Key points:

- Chickpea sown into flattened residue had lower (av. 1.00C) minimum temperatures compared to standing residue.
- Chickpea sown into flattened residue had higher (av. 3.40C) maximum temperatures compared to standing residue.
- Stubble thresholds are unknown at this stage.

Stubble affects soil physical properties such as temperature and moisture. The effect on temperature is due to landscape features such as whether a paddock was on top of a hill, on a hill slope, or at the lower end of a slope because cold air (due to its higher density) tends to flow downhill and settle in the lower parts of the landscape, leading to colder pockets where temperatures decline the most.

Stubble cover also affects air and soil temperature. During the day, the stubble reflects radiation due to its 'albedo'. A bare, darker soil absorbs more solar radiation than a stubble-covered soil and warms up more readily. The stubble also acts as insulation—it contains a lot of air which is a poor conductor of heat.

Finally, the stubble affects the moisture content of the soil. It takes more heat to warm up moist, stubble-covered soil than dry, bare soil. This causes soil temperature of a bare soil to be higher than stubble-covered soil during the day (especially in the afternoon). At night, however, the bare soil loses more heat than stubble-covered soil due to the lack of insulation (the air-filled mulch being a poorer heat conductor). This is especially noticeable when skies are clear. The air above the bare soil is therefore warmer during the night than the stubble-covered surface. This can affect canopy temperature profiles in crops.

In a recent trial, the temperature of stubble and the subsequent impacts on chickpea crops in NSW were explored.

In this trial, PBA HatTrick⒫ was sown at 30 plants/m² into paired 0.50 m rows with a skip row configuration leaving a gap of 1.0 m between skip rows.

Tiny tag™ temperature sensors were placed in mini Stevenson screens within chickpea experimental plots to measure temporal changes in temperature at ground level. Temperature sensors were placed between 1.0 m wide rows in:

1. plots sown into standing stubble with bare soil between chickpea rows
2. plots sown into flattened stubble with surface stubble between chickpea rows

The sensors recorded temperature every 15 minutes and were left in the plots right through to harvest in mid-December.

Chickpeas were sown into 5.84 t/ha of wheat stubble, either standing or flattened.

Standing stubble plots with bare soil between rows:

- had minimum temperatures 1°C warmer at the base of the canopy than surface-stubble plots during vegetative period
- had maximum temperatures -3.4°C cooler at the base of the canopy than surface-stubble plots during flowering and grain fill period
- recorded five days with maximum temperatures >35°C compared to 27 days of maximum temperatures >35°C where stubble was flattened.

Plant components for the stubble treatments are shown in Table 2. Plants sown into bare soil between standing wheat rows had higher grain yields which were achieved through more pods being set and more seeds being produced per square metre.

Table 2: *Effect of stubble treatment on selected plant components.*

Stubble	DM/m² (g)	Grain/m² (g)	Seeds/m²	Pod No/m²	Seeds/pod	HI
Bare soil	706	270	1072	815	1.3	0.38
Straw	526	226	908	538	1.7	0.43

Source: GRDC

Conclusions

- Flattened surface residue led to lower minimum temperatures in crop than standing residue.
- Flattened residue had higher maximum temperatures during flowering and grain fill than standing residue.
- Flattening and spreading residue can increase crown rot infection in the following wheat crop.
- Keep wheat stubble standing in defined rows and sow chickpeas between wheat rows. [14]

Bunching and clumping of stubble

Stubble bunching or clumping can occur when sowing into retained stubble as a result of blockages during sowing. These mounds of stubble are often picked up in the header front, causing mechanical blockages and contamination of the sample if they contain excessive amounts of soil.

14 Verrell, A. (2016). GRDC Update Papers - Stubble and its impact on temperature in chickpea crops. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Stubble-and-its-impact-on-temperature-in-chickpea-crops

MORE INFORMATION

Wide rows and stubble retention

Determining best stubble management

Management options for dealing with stubble clumping include:

- use of a no-till (disc) seeder or other seeder capable of handling heavy stubble
- modification of existing air-seeders (tyne shape and lifting some tynes)
- sowing before soil and stubble becomes too wet
- use of rotary harrows to spread and level stubble and sow between old plant rows, aiming to leave stubble standing

Standing stubble can be slashed or burnt if sowing equipment with good trash flow is not available. [15]

1.1.10 Soil testing guide

Accurate soil tests allow small landholders to maximise the health of their soils and make sound decisions about fertiliser management to ensure crops and pastures are as productive as possible (Figure 4).

Identifying potential soil limitations enables landholders to develop an action plan (such as an appropriate fertiliser program) to reduce the potential of 'problem' paddocks.

Figure 4: *Terrier automatic soil sampler.*

Source: DAFWA

Soil health looks at all aspects of the soil together, including the physical, chemical and biological components, rather than each component separately.

Healthy soil requires a balance between inputs and outputs and regular soil tests provide a valuable monitoring tool to keep an eye on soil nutrient levels and other key characteristics such as pH and salinity.

A soil imbalance can affect the ability of plants to absorb any applied fertiliser, wasting time and money. A combination of soil tests, on-farm observations and historical records will assist in determining soil health.

Soil testing is a useful tool to provide information to support decisions about fertiliser application, however it is important to combine test results with other information, such as specific crop or pasture requirements, available funds and fertiliser cost, methods of application and potential income from the crop or pasture being grown.

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

Accurate results

Soil test results are only as accurate as the samples taken from the paddock and how they are handled leading up to laboratory analysis. If the samples do not truly reflect the soils in a certain paddock the test results are likely to suggest an inaccurate picture of soil fertility.

Sampling not only depends on how the sample is taken but when and where.

There are four main steps in soil sampling:

- collecting representative samples
- laboratory analysis
- interpretation of test results on which to make decisions
- recording the results and actions taken for future reference

Taking the test

There is more to soil testing than analysing the soil's nutrient status. The process incorporates the sampling procedure, soil analysis and interpretation of the results leading to a sound recommendation.

Before collecting soil samples, consult a local agronomist to discuss the need for additional tests such as deep soil nitrogen tests. In most soils the nutrients are concentrated in the top 10 cm of soil, so ensure samples are consistently taken to this depth.

When to collect samples

Changes in soil moisture, plant growth stage and decomposition of organic matter all affect soil nutrient levels. For example, available nutrients can be low in soil samples collected during spring as nutrients are still in the plant and are not returned to the soil until after decomposition.

Check with your local agronomist as to the best time to collect soil samples in your area. Most comparisons are based on mid–summer (January to March) sampling when the soil is dry.

Regular tests build better profile

Because many factors influence soil test results, soil analysis for one season is not conclusive. Subtle differences in soil type can impact significantly on the availability and exchange of nutrients between the soil and plants so it is important to test soil regularly.

Testing the soil at the same time each year improves the comparison of results between years and builds a clear profile of soil health over time. It's also to take tests from the same site to monitor change of nutrients over time.

Collect enough samples to make up a representative picture of a paddock. It is better to over-sample, as this will provide a more accurate picture of the soil and will help reduce unnecessary fertiliser application.

Selecting your samples

Sampling often limits the success of soil testing. One hectare of soil to a depth of 10 cm contains about 1300 t of soil. A 10 g subsample sent to a laboratory represents only one part in 1300 million. So ensure your samples are representative.

To increase test result accuracy, avoid sampling soil near fences, trees, troughs, headlands, dams, stock tracks and clumps of manure, fertiliser dumps, fertiliser bands from the previous year, burnt heaps, areas of abnormally good or poor growth, or poorly drained areas.

Also avoid collecting samples from areas where fertiliser, gypsum or lime have been applied during the preceding three months. Wet soil can alter test results due to microbial activity and mineralisation.

Account for variability

Variability of soil is often overlooked.

Most soils in Western Australia (WA) are not uniform and comprise different soil types and slopes. Even individual paddocks often have variations in soil surface depth, soil type and nutrient levels, which can be significant over relatively short distances.

Many soil types can be found in a single paddock. This, combined with management practices, can lead to varying nutrient levels within and across paddocks. Even if the paddock has a uniform single soil type, stock can spread nutrients unevenly through urine and dung. Management can concentrate or spread nutrients through clearing, burning, grazing or hay production.

Where soil differences within a paddock are obvious and areas can be treated differently, take separate samples from each area.

Where there is more than one soil type, take about 20 cores from each major soil type. Ensure each soil type is sampled and labelled separately to allow for individual analysis.

To increase productivity on larger properties it is worthwhile classifying the land and soil types and ensuring samples are only collected from within a specific land and soil type.

Sampling sites

Take samples from across a paddock using a dedicated soil sampling tube or 'pogo'. Take at least five (preferably more) samples per hectare, covering the entire area.

Keep in mind that a hectare is 100 m × 100 m and to take five samples diagonally will involve taking samples about 30 m apart in a zig-zag pattern.

If the paddock is predominantly of one soil type, take at least 40 cores, each to a depth of 10 cm. For each soil type, bulk all samples together, thoroughly mix and take a 500 g subsample to be sent to the laboratory with clear labels.

Note in your records the pattern that you used to collect samples. Following the same pattern in future years will provide a clearer picture of soil fertility trends.

Handle with care

Collect cores in a clean plastic bag and label clearly. Do not use second-hand containers or touch soil samples with bare hands as this will contaminate the sample and affect the test results.

Air-dry samples by leaving the top of the bag open to the air if there is a delay between sampling and posting. Send samples to the laboratory early in the week if possible to avoid postal delays over weekends.

Prepared soil sampling kits are available from most rural supply stores. If using an off-the shelf kit read the instructions carefully as they may have specific instructions.

Interpreting the results

A number of laboratories are available to test and analyse your soil samples. Some services offer recommendations relating to the test results.

Contact your local agricultural consultant, agronomist or rural supply store for the contact details of available soil testing and support services in your region.

How to take a soil sample

To obtain an accurate soil analysis, the sample cores need to be taken correctly. Before taking samples, plan how many samples are required and from where they will be collected in the paddock.

Ensure the stainless steel sampling tube and collection bags (use new bags for each sample) are clean before taking samples, including inside the steel tube. If using oils on clay soils, ensure they are free of nitrates and carbon.

Most soil samples are taken from the top 100 mm of surface soil. Adjustable soil sampling probes often will have marks at 100 mm intervals.

If no mark exists set the depth stop at 100 mm using a ruler. It is vital all samples are taken from the same depth.

Zone the paddock based on soil type or yield potential and then take a representative sample from those areas (Figure 5).

Agronomist's view

For large paddocks, plan to take at least 25 cores in a grid or zig-zag pattern (Figure 5). Paddocks of more than 50 ha will require more core samples (minimum of 30 cores).

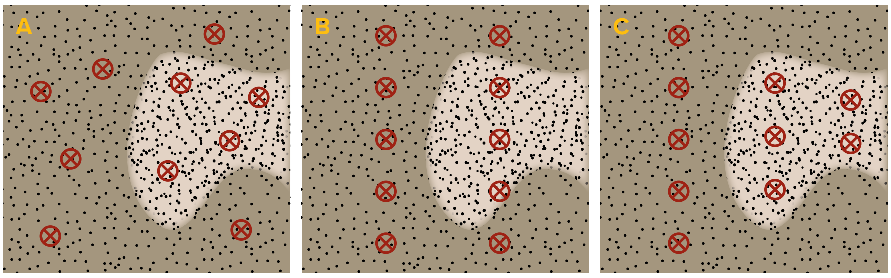

Figure 5: *Sampling strategies used to create a composite sample that integrates variation across different soil types (A and B); and a strategy to describe variation by sampling zones and analysing samples separately (C). A: haphazard samples strategically located to approximate the relative representation of different soil types. B: samples taken along transects intersecting different soil types. C: equal numbers of samples from each zone.*

Source: Soilquality.org

If there are two or three distinct soil types in a paddock of more than 100 ha, treat them as separate paddocks. In WA, it is recommended to take 4–8 samples within a paddock (each sample being at least 12–15 cores), each taken from within a land management unit in the paddock.

Before sampling, remove any debris from the soil surface, without disturbing the soil. Do not scuff away any plant material from the surface as this will lead to a loss of surface soil. Push in the sample tube straight until the depth stop contacts the ground.

Half-turn the sample tube and then remove it from the ground, taking care not to lose any soil from the end of the tube.

In light soils, the whole tube might need to be pushed toward the ground and a finger placed over the end of the core while the tube is parallel to the ground to ensure the soil does not fall out.

Place a sample bag over the upper end of the tube and invert, emptying the core into the bag. Tap the tube with the palm of a hand to loosen the core if required.

Soil tests can be a great tool in determining the health of your soils and in turn, maximise their productivity. [16]

16 DAFWA (2016). Soil sampling and testing on a small property. https://www.agric.wa.gov.au/soil-productivity/soil-sampling-and-testing-small-property?page=0%2C2

1.2 Paddock rotation and history

1.2.1 Break cropping

- A break crop is any crop sown to provide diversity to help reduce disease, weed and pest levels in a paddock.
- Choice of break crop type is determined by soil type and regional climate; crop sequence is determined by market and agronomic factors.
- Sourcing regional information from research organisations, agronomists, consultants, other farmers and industry bodies is essential when selecting the most suitable crop type and varieties.

Break crops generally refer to a pulse or oilseed crop grown instead of cereals. The decision not to grow wheat but to grow and choose a break crop is based on many factors including the relative profitability of the crops, yield by price, the cereal disease pressure, herbicide resistance and personal preference.

MORE INFORMATION

GRDC Break crop benefits Fact Sheet.

1.2.2 Chickpea as a rotation crop

Chickpea is well-suited to rotation with cereal and canola crops. Determining the most suitable cereal–pulse–oilseed rotation requires careful planning. There are no set rules and it is best to plan a separate rotation for each cropping paddock.

The major aim should be to achieve sustainability and the highest possible overall profit, but to achieve this, the rotation must be flexible enough to cope with key management strategies such as; maintaining soil fertility and structure, controlling crop diseases, exploiting plant available water, managing farm business risk and controlling weeds and their seed-set (Table 3). The same pulse should not be grown in succession, and extreme care must be taken if growing the same crop in the same paddock without a spell of at least three years. For disease management, it is recommended to aim for a break of at least four years between chickpea crops. [17] Successive cropping with the same pulse is likely to result in a rapid build-up of root and foliar diseases as well as weeds. Where possible, alternate the type of pulse crop being grown in a continuous rotation with cereals. Following dunfield pea or faba bean, leave two years before sowing chickpea. It is almost impossible to grade volunteer peas out of chickpea.

Table 3: *Advantages and disadvantages of including chickpeas as a crop rotation.*

Advantages	Disadvantages
Chickpea is a break crop that can be used successfully in rotations to effectively break the lifecycle of cereal root diseases like take-all and crown rot. Chickpea plants fix their own nitrogen. They have an extensive and deep root system. Chickpea can be sown relatively late compared to wheat, which can spread the demand for machinery and labour. Chickpeas can improve soil friability. Can expand weed-control options Don't require much additional equipment. Can be sown as an opportunity crop if seasonal conditions (full profile after summer rain) allow in lower rainfall districts. Assist in snail control as chickpeas are not attractive for snail multiplication.	Chickpea is less competitive against weeds than some other crops. Crop-topping to prevent weed seed set is not recommended in chickpea. Chickpea is not known to break up hard pans or compacted layers in the soil profile. Nematodes are a major drawback to planting chickpeas before wheat.

17 Pulse Australia. Southern Pulse Bulletin PA 2012 #08. Chickpea disease management strategy. http://pulseaus.com.au/storage/app/media/crops/2012_SPB-Chickpea-disease-management.pdf

In most situations, chickpeas can increase soil N by up to 35 kg nitrate-N/ha and yields of following wheat crops by up to 1 t/ ha, with an additional 1% of protein. Well-grown chickpea crops have been found to contribute up to 51 kg N/ha to the subsequent cereal crop. [18] In one study, the benefit of chickpea was equivalent to the application of 60 kg N/ha as fertiliser. [19]

It is often better to follow chickpea with barley rather than wheat. While older chickpea varieties were a host for the root lesion nematode *(Pratylenchus neglectus, P. thornei)*, newer varieties are not as susceptible to root lesion nematode multiplication. [20] Note that it is important to test soil for nematodes numbers if following chickpeas with a cereal other than barley, that may be more susceptible to yield loss.

Double-cropping pulses after cereals has been encouraged, except when stored soil moisture contents are low. The disadvantages of including pulses in the rotation are possible soil erosion losses due to the lower stubble levels produced and the chance of a greater volatility in prices associated with pulses. [21]

NOTE: Do not sow on to a field pea or faba bean stubble. Do not sow for two years after a dun field pea type or after faba bean. It is almost impossible to grade volunteer peas out. [22]

WATCH: Over the Fence: Chickpea redeemed as 'soil conditioner'.

1.2.3 Pulse effects on cereal yield

Pulses and cereal crops are complementary in a cropping rotation. This means crops benefit subsequent crops through processes related to disease, weeds, rhizosphere microorganisms, herbicide residues, residual soil water and mineral N. They may also include two recently discovered processes. One is growth stimulation following hydrogen gas released into the soil by the legume–rhizobia symbiosis. The other is a drain on assimilates when the roots are strongly colonised by the hyphae of *Arbuscular mycorrhizal* fungi built up by a previous colonised host crop.

Pulses fix their own N, leaving available N in the soil for the following cereal crop. Pulses also play a vital role in helping manage major cereal root diseases,

18 Cox, H. W., Strong, W. M., Lack, D. W., & Kelly, R. M. Profitable double-cropping rotations involving cereals and pulses in central Queensland.

19 Marcellos, H., Felton, W. L., & Herridge, D. F. (1993). Crop productivity in a chickpea-wheat rotation. In Proceedings 7th Australian Agronomy Conference (pp. 276–278).

20 Pulse Australia. Chickpea production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

21 Cox, H. W., Strong, W. M., Lack, D. W., & Kelly, R. M. Profitable double-cropping rotations involving cereals and pulses in central Queensland.

22 Pulse Australia. Chickpeas in South Australia and Victoria. http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpeas-SA-Vic.pdf

particularly crown rot, by allowing more time for the cereal stubble to break down between host crops.

The combination of higher soil N and reduced root diseases is cumulative and can result in a dramatic increase in subsequent cereal yields. However, it is important to remember that the benefits of N fixation from pulses is not guaranteed. The amount of N fixed is determined by how well the pulse crop grows, reflecting the effectiveness of nodulation, seasonal conditions, crop management, and the level of nitrate in the soil at sowing. Soil nitrate suppresses nodulation and N fixation, hence high soil nitrate means low N fixation (Figure 6).

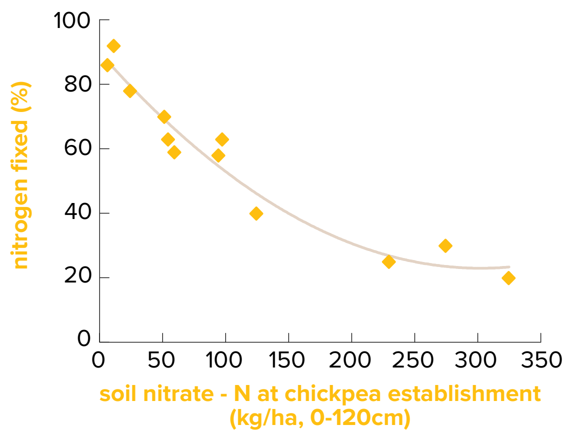

Figure 6: *Effect of soil nitrate nitrogen on nitrogen fixation by chickpea*

Source: J.A. Doughton et al 1993

Nitrate – N benefit for following cereals

The nitrate-N benefit from chickpea over a range of grain yields has been calculated from trials in northern Australia and is shown in Table 4. The terminology is important to an understanding of N budgets for chickpea and faba bean:

- 'Total N fixed'—the N fixed in both aboveground (shoots) and belowground (roots and nodules) biomass. With chickpea, 50% of total crop N is below ground.
- 'Nitrogen balance'—the difference between N inputs to the pulse crop (N fixation + N applied) and N outputs (N harvested in grain or hay + N lost (volatilised) from the crop and soil).
- 'Nitrate-N benefit'—the extra nitrate-N available at sowing in soil that grew a pulse crop in the previous season, compared with soil that grew a cereal crop.
- 'Harvest index' (HI)—for different crops, the relationship between shoot dry matter and grain yield (i.e. HI) may vary according to season and management.

By understanding the development and measurement of crop biomass and the factors that influence HI, better N and rotation management decisions can be made. [23]

23 Peoples, M. B., Schwenke, G. D., Felton, W. L., Chen, D., & Herridge, D. F. (2003). Effects of below-ground nitrogen on N balances of field-grown fababean, chickpea, and barley. *Crop and Pasture Science*, *54*(4), 333-340.

Table 4: *Nitrate-N benefit from chickpea, over a range of grain yields (all values are kg/ha).*

Grain yield (t/ha)	Shoot dry matter (t/ha)	Low soil nitrate at sowing (50 kg N/ha)			Mod soil nitrate at sowing (100 kg N/ha)		
		N fixed	N balance	Nitrate-N benefit	N fixed	N balance	Nitrate-N benefit
1.0	2.4	31	–3	16	13	–21	4
1.5	3.6	74	22	28	47	–5	13
2.0	4.8	120	49	44	84	12	24
2.5	6.0	157	66	48	111	21	38
3.0	7.1	198	88	52	141	31	52
3.5	8.3	231	102	57	164	35	64
4.0	9.6	264	116	61	188	39	69

Source: Grain Legume Handbook (2008)

Crown rot

Crown rot (caused by *Fusarium pseudograminearum*) is a major constraint to winter cereal production in Australia. The disease effectively blocks the base of infected tillers, preventing water movement from the roots through the stems and producing prematurely ripened heads (whiteheads) that contain no grain or lightweight shrivelled seed. Crown rot is a stubble-borne pathogen and survives as mycelium (cottony growth) inside cereal and grass weed residues.

Rotations to non-host winter pulses, oilseeds or summer crops are the most important component of an integrated disease management system. The effectiveness of a break crop in reducing yield loss to crown rot is a function of both inoculum survival (decomposition) and water-use pattern of the break crop. Chickpeas tend to use less water during the season than canola and generally do not root as deeply. Cereal crops following chickpea may experience reduced moisture stress through this water saving, thus reducing the development of whiteheads in infected tillers.

Yield response in a following cereal crop as a result of the benefit of reducing crown rot is a function of a break crop's effect on inoculum survival, soil water and Nitrogen (Figure 6). [24]

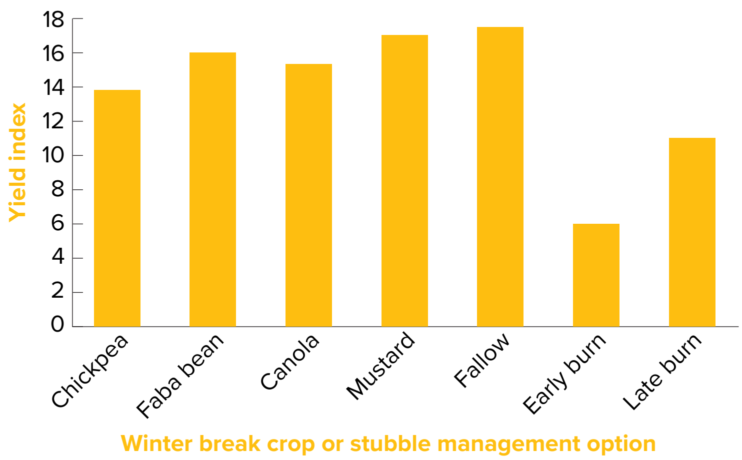

Figure 7: *Yield index of wheat after various break crops of management options compared with continuous wheat*

Source: NSW DPI, 2006

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

WATCH: Over the Fence West: VRT and legume rotations deliver yield boost and input cost cut.

1.2.4 Understanding soils and pulse crop constraints

If poor crop growth and yield are occurring in a paddock, despite good rainfall and soil moisture, the factor constraining yield needs to be determined (Figure 8).

Figure 8: *Aerial shot of chickpea crops showing wide-scale crop loss due to sodic/saline conditions.*

Understanding growth constraints will influence crop choice and management. Constraints may be soil related or biological (e.g. disease, an insect pest, or a nematode). Some guidelines are provided in Table 5 and 6 below to assist in testing and diagnosis.

Table 5: *Indicative signs and likely causes of constraints to plant growth.*

Likely constraint	Indicative signs of a constraint	Possible solution
Biological	Roots may show dark lesions, knotting or discoloration (e.g. honey or brown coloured)	Identify the problem. Use crop rotations and farm hygiene and grow more resistant crops or varieties. Use fungicide or insecticide seed treatment, appropriate disease or pest control. Encourage the build-up of beneficial organisms through supplying organic substrate (e.g. stubble retention). Use direct drilling or no-till
Nutrient deficiency	Leaves or stems show characteristic symptoms of nutrient imbalance	Identify the nutrient disorder (soil or plant test). Apply appropriate fertiliser as granular, liquid injection or foliar application. Improve agronomy practices to build a healthier soil
Soil surface sodicity	Soil surface shows waterlogging, hard setting or crusting. Water ponds for several days after rain	Applying gypsum can improve soil surface sodicity by flocculating soil and so improving infiltration and exchange of sodium for calcium
Physical	Roots are deformed or may grow at a right angle. Rooting depth is restricted by presence of stones or rock, by a dense clay layer, hardpan, a plough layer or traffic compaction	Deep ripping may benefit some hardpans or compacted layers. Some ameliorant may need to be incorporated at the same time (e.g. organic matter, gypsum, lime). Controlled traffic will be needed afterwards. Growing plants with a taproot that is deep rooting can help
Chemical	There is an absence of fresh roots in the rooting zone (e.g. top 1 m of soil). The subsoil remains wet after a dry finish	Salinity: avoid sensitive crops such as chickpea and lentil, and grow more tolerant crops and varieties. If subsoil drainage is improved, then this can help to leach salts from the upper soil layers Acidity: use lime to as an ameliorant on acidic soils Sodicity: apply gypsum Alkalinity: elemental sulfur can help acidify highly alkaline soils, but large quantities will be required on heavy clay soils
Subsoil sodicity	Subsoil is lacking drainage. Structure of subsoil is coarse or dense	Sodicity: apply high rates of gypsum, but incorporation is needed, otherwise adequate rainfall and time are needed for gypsum to be effective in subsoils

Source: Grain Legume Handbook 2008

Table 6: *Testing and decision process to follow in determining which soil constraints apply.*

Electrical conductivity (EC, 1:5 water) (dS/m)					
Check soil for EC in surface and subsoil					
Low EC <0.3 dS/m in top 10 cm			High EC >0.3 dS/m in top 10 cm		
Low EC <0.7 dS/m in subsoil			High EC >0.7 dS/m in subsoil		
Plant growth is not affected by salinity:			Plant growth is affected by salinity:		
Check soil for exchangeable sodium percentage (ESP) and/or dispersion			**Check soil for sodium and chloride concentration**		
No dispersion (ESP <6)		Dispersion (ESP >6)	Cl >300 mg/kg in top 10 cm soil	Cl <300 mg/kg in top 10 cm soil Cl <600 mg/kg in subsoil	
Check soil pH (1:5 soil:water)			Cl >600 mg/kg in subsoil	**Check for gypsum crystals and sulfur concentration**	
pH <5.5	pH >8.0			S >100 mg/kg	S <100 mg/kg
Acidity constraint	**Alkalinity constraint**				
		Sodicity constraint			
			Osmotic effect due to high salt and Na/Cl toxicity,		
				High EC due to gypsum; no constraint to crop growth	**No gypsum; other salts are causing the problem**

Source: Qld Natural Resources and Water Bulletin

For more information on soil constraints on chickpeas, see Section 14: Environmental issues.

1.3 Fallow weed control

Chickpeas are slow to emerge and initially grow slowly. They are notoriously poor competitors with weeds. Even moderate weed infestation can result in severe yield losses and harvesting problems. The best form of weed control is rotation and careful selection of paddocks largely free from winter weeds, for example in areas with a sequence of clean winter fallows (Figure 8).

Figure 9: *Fallow paddock.*

Source: Farmers Weekly Photo: Tim Scrivener

Uncontrolled heavy weed growth during the summer fallow period can reduce the yield of the subsequent crop by:

- robbing subsequent crops of available soil nitrogen
- decreasing the amount of stored soil moisture
- reducing crop emergence due to the physical and/or chemical (allelopathic) interference at seeding time.

A study by the Cooperative Research Centre (CRC) for Australian Weed Management found that summer weeds can lock away large amounts of nitrogen in the weedy biomass, rendering it unavailable for crop growth. Weed burdens of 2.5 tonnes per hectare can cause a net loss of available soil nitrogen and burdens of more than 3 t/ha can reduce subsequent wheat yields by as much as 40%.

In another Grains Research and Development Corporation (GRDC) funded study in South Australia, it was found that the major impact of summer weeds was on soil moisture. Complete weed control increased available soil moisture at one site by over 11 millimetres. The CRC study also found that as weed biomass increased, water losses increased. The magnitude of the water loss and its importance to the subsequent grain yields however, varied from site to site.

Summer weeds can also impede crop emergence. Moderate to heavy uncontrolled weed growth can result in reduced crop emergence in minimum tillage systems due to the impenetrable layer left on the soil surface. Wireweed for example, has long tough and wiry stems which can get caught in the tynes at seeding. [25]

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

Benefits of fallow weed control are significant:

- Conservation of summer rain and fallow moisture (this can include moisture stored from last winter or the summer before in a long fallow) is integral to winter cropping in the northern region, particularly so as the climate moves towards summer-dominant rainfall.
- Modelling studies show that the highest return on investment in summer weed control is for lighter soils, or where soil water is present that would support continued weed growth. [26]

Trials exploring methods for summer grass control have found:

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

25 S Peltzer. (2016). Summer Weeds. DAFWA. https://www.agric.wa.gov.au/postharvest/summer-weeds

26 GRDC (2012) Make summer weed control a priority—Southern region. Summer Fallow Management, GRDC Fact Sheet January 2012, https://www.grdc.com.au/~/media/8F16BE33A0DC4460B17317AA266F3FF4.pdf

WATCH: Fallow spray techniques explored for WA's low rainfall zones.

1.3.1 Management strategies

Controlling summer weeds early will conserve valuable soil nitrogen and moisture for use by the crop during the following season. A Western Australian grower at Salmon Gums can demonstrate an average farm crop yield increase of 400 kilograms per hectare since the adoption of consistent summer weed control.

Herbicide application

Broadleaf weeds and herbicide resistant grasses can cause major problems and a careful management strategy must be designed well in advance. If possible, control weeds in the year prior to sowing chickpea or avoid paddocks with specific weeds that cannot be controlled by available herbicides. [27]

Summer weed control can be expensive but is necessary to prevent problems with excessive growth and/or moisture and nitrogen loss from the soil. When using herbicides:

- Water rates should be kept high (at least 60 litres per hectare).
- Add a surfactant and/or spraying oil to all post-emergent treatments unless otherwise directed on the label.
- Do not spray stressed plants.
- Spray grazing can be effective at high stocking rates.
- Glyphosate, 2,4-D, metsulfuron, atrazine and triclopyr are the most common herbicides used for summer weed control.
- Where summer grasses are present, glyphosate at rates around 2 L/ha are generally required.
- Metsulfuron provides cheap control of wireweed, triclopyr is generally preferred for melon control and atrazine for small crumbweed (also known as mintweed or goosefoot).
- 2,4-D controls a wide range of broadleaved weeds and is preferred if stock are available for spray grazing. The ester formulations are usually more effective for summer weed control because they are oil soluble and more able to penetrate the waxy surfaces or stubble.
- Moisture stress in weeds is common in summer and reduces the effectiveness on most herbicides. This can be partially overcome by spraying early in the

27 Pulse Australia. Chickpea production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

morning. However, at this time of day, inversions may be present which could lead to excessive drift. Avoid spraying during still conditions. [28]

Herbicide options for broad-leaved weed control are very limited. If the standard treatment of post-sow pre-emergent simazine is unlikely to provide adequate control, growers need to consider alternative control strategies:

- the use of Balance®
- use of trifluralin
- inter-row cultivation is only an option in wide row systems
- inter-row shielded sprayer (glyphosate) is only an option in wide row systems
- post emergent Broadstrike® may be damaging (refer to label)
- directed post-emergence sprays of Broadstrike® and/or simazine

Herbicide options for grassy weeds may be very limited if herbicide resistant ryegrass is present. If the standard trifluralin pre-sowing treatment and post-sow pre-emergent simazine are unlikely to provide adequate control, growers will need to consider alternative control strategies:

- the use of Balance®
- use of group A herbicides post-emergent if herbicide resistance not present
- inter-row cultivation is only an option in wide row systems
- inter-row shielded sprayer (glyphosate) is only an option in wide row systems
- crop topping or weed wiping are not options to prevent seed set of escape weeds

Avoid paddocks with high numbers of herbicide resistant weeds unless a programmed strategy is in place. [29]

Double-knock strategies

Double-knock refers to the sequential application of two different weed-control tactics applied in such a way that the second tactic controls any survivors of the first. Most commonly used for pre-sowing weed control, this concept can also be applied in-crop. [30]

Consider the species present, interval timing and water rate. Double-knock herbicide strategies are useful tools for managing difficult-to-control weeds, but there is no 'one size fits all' treatment. The interval between double-knock applications is a major management issue for growers and contractors. Shorter intervals can be consistently used for weeds where herbicides appear to be translocated rapidly (e.g. Awnless barnyard grass, ABYG) or when growing conditions are very favourable. Longer intervals are needed for weeds where translocation appears slower (e.g. fleabane, feathertop Rhodes grass and windmill grass) or where environmental conditions like temperature and soil moisture have affected weed growth. Critical factors for successful double-knock approaches are for the first application to be on small weeds and to ensure good coverage and adequate water volumes, particularly when using products containing paraquat. Double-knock strategies are not fail-proof and rarely effective for salvage weed-control situations unless environmental conditions are exceptionally favourable.

Grazing summer weeds

Summer weeds can provide quality feed for sheep, especially when there is no other green feed around. Windmill grass for example has a moderate forage value and has a digestibility of 35-68%. Perennial grasses such as windmill grass maintain some quality feed into summer especially with summer rainfall and when the flowering stage is delayed. Annual grasses such as soft brome (*Bromus hordeaceus*) and

28 S Peltzer. (2016). Summer Weeds. DAFWA. https://www.agric.wa.gov.au/postharvest/summer-weeds

29 Pulse Australia. Southern Pulse Bulletin PA 2010 #05 – Chickpea checklist for southern growers. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-checklist-south.pdf

30 C Borger, V Stewart, A Storrie. Double knockdown or 'double knock'. Department of Agriculture and Food Western Australia

MORE INFORMATION

[Summer weed fallow management: a reference manual for grain growers and advisers in the southern and western grains regions of Australia.]

[Summer weeds]

barley grass have moderate digestibility but quickly lose quality as they become reproductive.

Be wary, however, that some summer weeds create grazing problems. Caltrop is toxic to sheep and can cause photosensitization (abnormal sensitivity to sunlight) leading to inflammation of exposed skin and sometimes death. If seed set is not prevented, the spiny burrs from infestations can cause lameness and infection, particularly in young lambs because their hoofs are soft.

Crumbweed (*Chenopodium pumilio*) can also be toxic to sheep causing cyanide poisoning, profuse scouring and sudden death. It emerges in spring and summer and can also reduce crop establishment in the following season (allelopathic). It is native to Western Australia.

For more information on weed management, see Section 6: Weed Control.

1.4 Fallow chemical plant-back effects

Plant-back periods are the obligatory times between the herbicide spraying date and safe planting date of a subsequent crop. Some herbicides have a long residual persistence. The residual is not the same as the half-life. Although the amount of chemical in the soil may break down rapidly to half the original amount, what remains can persist for long periods, e.g. sulfonylureas (chlorsulfuron). This is shown in Table 7 where known. The rate of decay is influenced by soil pH and moisture levels.

Check the AVPMA website for more details.

Table 7: *Residual persistence of common pre-emergent herbicides, and noted residual persistence in broadacre trials and paddock experiences.* [31]

Herbicide	Half-life (days)	Residual persistence and prolonged weed control
Logran® (triasulfuron)	19 (Note that this estimate is pH and moisture dependent)	High. Persists longer in high pH soils. Weed control commonly drops off within 6 weeks
Glean® (chlorsulfuron)	28–42	High. Persists longer in high pH soils. Weed control longer than Logran
Diuron	90 (range 1 month to 1 year, depending on rate)	High. Weed control will drop off within 6 weeks, depending on rate. Has had observed long-lasting activity on grass weeds such as black/stink grass (Eragrostis spp.) and to a lesser extent broadleaf weeds such as fleabane
Atrazine	60–100, up to 1 year if dry	High. Has had observed long-lasting (>3 months) activity on broadleaf weeds such as fleabane
Simazine	60 (range 28–149)	Med-high. 1 year residual in high pH soils. Has had observed long-lasting (>3 months) activity on broadleaf weeds such as fleabane

31 B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

Herbicide	Half-life (days)	Residual persistence and prolonged weed control
Terbyne® (terbulthylazine)	6.5–139	High. Has had observed long lasting (>6 months) activity on broadleaf weeds such as fleabane and sow thistle
Triflur® X (trifluralin)	57–126	High. 6–8 months residual. Higher rates longer. Has had observed long-lasting activity on grass weeds such as black/stink grass (Eragrostis spp.)
Stomp® (pendimethalin)	40	Medium. 3–4 months residual
Avadex® Xtra (triallate)	56-77	Medium. 3–4 months residual
Balance® (isoxaflutole)	1.3 (metabolite 11.5)	High. Reactivates after each rainfall event. Has had observed long-lasting (> 6 months) activity on broadleaf weeds such as fleabane and sow thistle
Boxer Gold® (prosulfocarb)	12-49	Medium. Typically quicker to break down than trifluralin, but tends to reactivate after each rainfall event
Sakura® (pyroxasulfone)	10-35	High. Typically quicker breakdown than trifluralin and Boxer Gold, however, weed control persists longer than Boxer Gold

Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the 'Protection of crops etc.' heading in the 'General Instructions' section of the label. [32]

In wheat-chickpea rotations avoid the use of fallow and in-crop residual herbicides such as Broadstrike®, Eclipse®, Flame® Grazon®DS, Lontrel® and metsulfuron (Ally®, Associate®, Lynx®,, Harmony®M, particularly during the summer fallow or weed control period (after November).

The use of long-term residual sulfonylurea herbicides such as Monza®, chlorsulfuron (Glean®, Lusta®) and Logran® in wheat should be avoided when re-cropping to chickpeas.

MORE INFORMATION

Herbicide residues in pulses

1.4.1 Herbicide residues in soil

Residues from herbicides used in the current or previous crop could impact on subsequent crop choice in rotations (Figure 10). Crop damage could occur if this is ignored, particularly where rainfall has been minimal. Pulse and other crop types differ in their sensitivity to residual herbicides so check each herbicide used against each crop type. Check herbicide history in paddocks for any chemical that may cause any detrimental effect to chickpeas. Herbicide choice in crops may have to accommodate the planning of a pulse crop next in the rotation sequence. For example, it could be

32 B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

10 months before a chickpea crop can be grown after use of an imidazolinone ('imi') herbicide, and likewise over 24 months after chlorsulfuron has been applied on high pH soils. [33]

Figure 10: *Herbicide residue affected plants appear pale and stunted.*

Source: DAFWA

Herbicides such as Group B (Logran®, Glean®, Hussar® and Ally®) typically pose the greatest threat if they are persistent in the soil when chickpeas are planted. Typical symptoms are stunting and yellowing of the plants if affected. Other herbicides to be wary of are LontrelTM, AmineTM (used over summer) and dicamba (used prior to cropping). These herbicides (in Group I) can cause twisting and growth distortions of plants. [34]

WATCH: GCTV16: Desi Chickpea – considering herbicide residuals.

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

34 M Witney, (2012). GRDC. Update Papers. Chickpea management and agronomy. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/07/Chickpea-management-and-agronomy

Conditions required for breakdown

Warm, moist soils are required to break down most herbicides through the processes of microbial activity. For the soil microbes to be most active, they need good moisture and an optimum soil temperature range of 18°C to 30°C. Extreme temperatures above or below this range can adversely affect soil microbial activity and slow herbicide breakdown. Very dry soil also reduces breakdown. To make matters worse, where the soil profile is very dry it requires a lot of rain to maintain topsoil moisture for the microbes to be active for any length of time. [35]

For more information, see Section 6: Weed control.

1.5 Seedbed requirements

Chickpea seeds are larger than peas or lentils, so they are less sensitive to seed placement than some other crops. However, a firm, yet friable, moist seedbed is still essential.

No-till

Under no-till conditions, avoid excessive amounts of surface residue in order to promote proper seed placement and early warm-up of the soil. Potential production fields must have a history of limited weed pressure since weeds can negatively impact seed yield and are strong competitors with chickpea plants. [36]

Chickpea and faba bean yields have been found to be higher after no-till than after cultivated fallows, also leading to better yield and protein responses in subsequent cereal crops. Growing chickpea under no-tillage rather than a cultivated fallow increases yields by an average of 11% and increases the following wheat crop by 0.9 tonnes per ha. [37]

Tillage

A smooth seedbed with most of the previous crop residue incorporated is good for chickpea growth (Figure 11). This will allow proper depth of planting as well as good seed-soil contact, which is essential for rapid germination and emergence. If moisture is short keep deep preplant tillage to a minimum to prevent excessive drying in the top 5–8 cm of soil. [38]

One study in Spain found that conventional tillage practices lead to better chickpea root development than no-tillage practices. [39] Another study in Pakistan found that conventional tillage reduced weed biomass in chickpea crops by 20% and increased yield by 2% compared to no-till practices. [40]

35 Dow AgroSciences. Rotational Crop plant-back intervals. http://msdssearch.dow.com/PublishedLiteratureDAS/dh_0931/0901b80380931d5a.pdf?filepath=au&fromPage=GetDoc

36 Chickpea production in the high plains. South Dakota State University Extension, University of Wyoming, University of Nebraska. http://www.agmrc.org/media/cms/ec183_435DBB048F8C5.pdf

37 W Felton. (2003). Chickpea increases no-till farming yields. Farming ahead No. 134.

38 E S Oplinger, L L Hardman, E A Oelke, A R Kaminski, E E Schulte, J D Doll. (1990). Chickpea (garbanzo bean). Alternative field crops manual. https://hort.purdue.edu/newcrop/afcm/chickpea.html

39 Muñoz-Romero, V., López-Bellido, L., & López-Bellido, R. J. (2012). The effects of the tillage system on chickpea root growth. Field Crops Research, 128, 76-81.

40 Jan, A., Amanullah, Akbar, H., & Blaser, B. C. (2012). Chickpea response to tillage system and phosphorus management under dryland conditions. *Journal of plant nutrition*, *35*(1), 64-70.

Figure 11: *Strategic tillage can provide control for herbicide-resistant weeds and those that continue to shed seed throughout the year. Here it has been used for control of barnyard grass in fallow.*

Source: https://grdc.com.au/Resources/Factsheets/2014/07/Strategic-tillage

1.6 Soil moisture

1.6.1 Dryland

Australia is the world's driest continent, yet only around 7% of Australia's grain crops are grown on irrigated soil, with the remainder produced under dryland conditions. [41] The majority of soils in the cropping region of WA are relatively low in clay and soil organic matter. Consequently, their inherent soil quality is naturally low. Sustainable management of the soil resource is therefore essential to the continued viability of the Western Australian agricultural industry. The State's main dryland cropping region extends from Geraldton in the mid-west to Esperance in the south. Dryland crops are typically grown on a broad hectare scale and rely on seasonal rainfall rather than irrigation. The climate in south-western Australia is Mediterranean, with hot dry summers where growers rely heavily on winter rain.

Chickpeas require greater than 350 mm annual rainfall, but there are opportunities to grow them in lower rainfall areas if adequate soil moisture is present at sowing (e.g. >20 mm of stored soil water at 0-60 cm depth). The best guide to assessing soil water storage is to put down several soil cores. [42]

Preserving dryland fertility

The Western Australian No-Tillage Farmers Association (WANTFA) is driving adoption of sustainable and profitable broad acre cropping systems by sharing farmer experiences and innovations from their research and field trials. Here are some of their key recommendations for preserving soil's biological fertility.

- Minimise soil erosion.
- Try to maintain/increase organic matter contents.
- Use diverse rotations.
- Select nitrogen fixing bacteria to match the host plant and soil characteristics.
- Calculate fertiliser applications to account for soil nutrient supply.

MORE INFORMATION

GRDC Strategic Tillage Tips and Tactics fact sheet.

41 Agribusiness review. (2014) Finding new ways for dryland farmers to stay profitable. http://business.nab.com.au/finding-new-ways-for-dryland-farmers-to-stay-profitable-6689/

42 Pulse Australia. Southern Pulse Bulletin PA 2010 #05–Chickpea checklist for southern growers. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-checklist-south.pdf

MORE INFORMATION

Surface water management

Subsurface water management

Water Quality Improvement Plans

Dryland crops near sensitive water resources

- Consider whether any addition to soil will change the physical and chemical environment.
- Remove practices that promote plant pathogens.
- Consider management practices and commercial products for their capacity to enhance soil fertility.
- Be patient. Soil biological processes take time to develop. [43]

1.6.2 Irrigation

Key points:

- Select fields with good layout and tail water drainage (Figure 12).
- Avoid high bulk density or high clay content soils that do not internally drain quickly.
- Avoid acid, saline or sodic soils (see levels below).
- Pre-irrigate or water-up to fill the soil profile wherever possible.
- Irrigate early at 60–70% of field capacity to avoid crop stress and soil cracking open.

Key tips for success:

- **Drainage**: Ensure the layout allows irrigation and drainage within eight hours.
- **Soil structure**: Good soil structure ensures good water infiltration, root penetration and internal drainage.
- **Subsoil moisture**: Pre-irrigate or water-up to achieve adequate soil moisture for uniform emergence and during the vegetative stage. Irrigate prior to flowering to ensure a good profile of moisture during flowering and pod fill.
- **Sown on time**: Sow recommended varieties within the preferred sowing window for your location.
- **Crop establishment**: Use good quality seed and germination-test retained seed (Figure 13). Aim for a plant population of 35 to 40 plants per square metre.
- **Adequate nutrition**: While chickpeas are efficient at extracting soil phosphorus it is wise to apply adequate phosphorus relative to the paddock history and soil-test results. Approximately 40 kg of P per hectare is required for a 4 tonne crop. Good inoculation procedures with the appropriate rhizobium should meet the N requirements of chickpeas, however low zinc and sulfur levels should also be addressed.
- **Soil moisture**: Check soil moisture regularly to ensure timely irrigations to avoid stress or possible crop damage. Moisture monitoring equipment is now available at reasonable prices and can assist in more precise measuring, particularly at depth. Ensure plants do not stress during the reproductive stage and have adequate available soil water for the entire growing season. [44]

43 Agribusiness review. (2014) Finding new ways for dryland farmers to stay profitable. http://business.nab.com.au/finding-new-ways-for-dryland-farmers-to-stay-profitable-6689/

44 Pulse Australia. Southern Pulse bulletin PA 2010 #17 – Irrigated chickpea management. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-irrigation.pdf

Figure 12: *Irrigated beds with damage from water remaining in the tail drain.*

Source: Pulse Australia

Figure 13: *Poor quality seed on the left – all seed was sown on the same day.*

Source: Pulse Australia

Irrigated chickpea crops can be very profitable and rewarding with well-managed crops yielding in excess of 3.5 t/ha. High yields have occurred across a wide range of soil types and irrigation layouts through a combination of correct paddock selection, precise irrigation scheduling and close attention to chickpea agronomy. In addition, chickpeas can contribute to crop rotations because of their ability to fix nitrogen and provide a disease and weed break for following cereal crops.

Full or supplementary irrigation of chickpea is common in districts where chickpea is grown in rotation with other irrigated crops, such as cotton. Management requirements for irrigated chickpea are the same as for dryland, but their sensitivity to waterlogging, for even a short time, can result in severe losses, particularly if the crop is also under stress from herbicides or disease.

Using sprinkler irrigation equipment reduces the risk of waterlogging, even during flowering and pod-fill, however there may be a higher risk of foliar disease, e.g. botrytis grey mould and ascochyta blight, due to the increased irrigation frequency and leaf wetness. [45]

Factors to consider when planning for irrigated chickpea production:

- Avoid heavy clay or dense soil types (bulk density >1.5) that do not drain freely and are subject to waterlogging.
- Select fields with an effective irrigation layout, such as beds or hills, and relatively good grades.

45 Pulses Australia. Chickpea Production: Southern and Western regions. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

- A border-check layout that is steeper than 1:800 grade is suitable provided there are short runs on free draining soils that can be irrigated quickly and do not remain saturated.
- Rolling may be required to flatten the ridges left by press-wheel furrows or to flatten clods.
- Irrigation can be used to activate and incorporate a number of pre-emergent herbicides.
- Pre-irrigate to fill the moisture profile prior to planting chickpea crops, unless there has already been sufficient rainfall. Watering-up is most effective in bed, row and sprinkler systems, but is not recommended for border-check layout unless soil moisture is insufficient to achieve a uniform germination.
- As a general rule, irrigation of the emerged crop should start early when there is a deficit of 30–40 mm and around 60–70% field capacity. Schedule irrigation using soil moisture indicators rather than the crop growth stage.
- Time irrigation application to prevent moisture stress during flowering and podding and to reduce the impact of high temperatures on yield, quality and grain size. This is particularly important with large kabuli types. Chickpea is very sensitive to waterlogging during flowering and podding so great care is required to provide adequate soil moisture without waterlogging.
- In furrow irrigation systems, water every second row to avoid waterlogging. Doubling up the number of siphons can increase water flow and reduce irrigation time.
- Aim to have watering completed in less than eight hours, and have good tail water drainage to avoid any waterlogging in the crop area.
- Avoid irrigating if rain is forecast for the near future.
- In border-check layouts and paddocks with heavy soil types or long runs: **if in doubt, do not water.** [46]

It is important for growers and agronomists to base yield expectations on the total water supply available. This includes a combination of the amount of soil water in the profile, likely in-crop rainfall and irrigation water supply. A general rule of thumb for chickpeas can be based on 1 tonne grain per megalitre water supply (per hectare).

To offset the good performances there are growers who have only achieved yields of 1.0–1.5 t/ha and some of the common causes have been:

- problems with poor crop establishment and vigour (seed quality, seedbed, herbicides)
- unsuitable soils limiting water extraction (sodic or saline subsoils)
- poor scheduling of in-crop irrigation
- restricted water supply limiting yield

Chickpeas are very sensitive to waterlogging and even if waterlogged for a short period of time, crop losses can be severe. This has particularly occurred where crops have been moisture stressed allowing soils to dry out to depth and often crack open (Figure 14). Waterlogging is a stress on a chickpea crop and when combined with other stresses such as moisture stress, damaged root systems, disease, herbicide injury, or sodic and saline soils can be a disaster. Watering during flowering or podfill when the crop is more sensitive further increases the risk of yield loss. [47]

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46 Pulses Australia. Chickpea Production: Southern and Western regions. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

47 Pulse Australia. Southern Pulse bulletin PA 2010 #17 – Irrigated chickpea management. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-irrigation.pdf

Figure 14: *Chickpea on the left received a very late irrigation.*

Irrigation techniques to reduce the period of waterlogging:

- for furrow irrigation, water every second row
- double-up siphons to speed up water flow.
- do not irrigate if rain is likely
- ensure that tail water drains away quickly

Spray irrigation

The risk of waterlogging is significantly reduced when using lateral move or centre-pivot irrigators compared to flood, as the amount and timing of water application can be better controlled. However, wet foliage from more frequent irrigations can increase the risk of fungal diseases particularly ascochyta blight and botrytis grey mould. Greater attention to disease management, monitoring the variety chosen in relation to disease resistance, is important. [48]

Irrigation management strategy for chickpea

- Pre-irrigate to fill the moisture profile before planting chickpea crops, unless there has already been sufficient rainfall. Watering-up is most effective in bed, row and sprinkler systems, but is not recommended for border-check layout unless soil moisture is insufficient to achieve a uniform germination. Ensure that seed placement allows at least 7 cm of soil above the seed if using Balance® or simazine and the soil surface is left flat to prevent herbicide leaching into the plant furrow.
- As a general rule, irrigation of the emerged crop should start early when there is a deficit of 30–40 mm and around 60–70% field capacity. Schedule irrigation using soil moisture indicators rather than the crop growth stage.
- Time irrigation application to prevent moisture stress during flowering and podding and to reduce the impact of high temperatures on yield, quality and grain size. This is particularly important with large kabuli types. Chickpea is very sensitive to waterlogging during flowering and podding so great care is required to provide adequate soil moisture without waterlogging.
- In furrow irrigation systems, water every second row to avoid waterlogging. Doubling up the number of siphons can increase water flow and reduce irrigation time.
- Aim to have watering completed in less than eight hours, and have good tail water drainage to avoid any waterlogging in the crop area.
- Avoid irrigating if rain is forecast for the near future.

48 Pulse Australia. Southern Pulse bulletin PA 2010 #17 – Irrigated chickpea management. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-irrigation.pdf

MORE INFORMATION

Irrigated Chickpeas – Best Practice Guide.

- In border-check layouts and paddocks with heavy soil types or long runs: **if in doubt, do not water.** [49]

IN FOCUS

High value kabuli chickpea production in the Ord River Irrigation Area

In the Ord River Irrigation Area (ORIA) kabuli chickpea is a high-value industry producing large seeded, high quality grain for domestic and export markets (Figure 15). The area sown to chickpea in the ORIA varies from 400 to 1000 ha per year.

Figure 15: *Irrigated chickpea crop in the Ord River Irrigation Area, WA.*

Source: DAFWA

Fertiliser

Soils in the ORIA are generally deficient in phosphorus (P), nitrogen (N) and zinc (Zn), therefore fertilisers are applied to compensate. Grower practice is to apply approximately 40 kg of P/ha, 3 kg Zn/ha, 10 kg sulfur (S)/ha and 45 kg N/ha However, these levels may be too high or unnecessary in some instances, particularly N.

There are indications that N might provide some benefit to the crop prior to nodulation. Inspection of nodulation in commercial crops in 1999–2000 indicated that active nodulation does not start until about five weeks after sowing. However, high levels of N could also adversely affect nodulation and care should be taken if applying higher rates.

Chickpeas are very efficient at utilising soil P. They secrete organic acids from their roots, which dissolve insoluble sources of P to provide water-soluble P for plant uptake. Hence, sites that have been cropped for several years may have adequate levels of residual P. Studies conducted in the ORIA have indicated that a soil P level of 24mg/kg is sufficient for chickpea production.

It is common practice in the ORIA to apply diammonium phosphate (DAP) at 200–300 kg/ha, as it is generally the least expensive form of P fertiliser available. However excess N is applied at this rate. It is now suggested that growers use 3:1 superphosphate/potash at 150–250 kg/ha.

Zinc deficiencies have been recorded on crops in the ORIA. The practice of applying Zn (3 kg/ha) in the form of zinc monohydrate has been common in recent years. However, build-up in soil Zn levels does occur and annual application may not be necessary. Soil levels above 2 ppm are generally adequate for most field crops grown on Kununurra clay soils in the ORIA.

49 Pulses Australia. Chickpea Production: Southern and Western regions. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

Irrigation

The scheduling of crop irrigation is a critical management strategy affecting kabuli chickpea yield and quality. For Kimberley, Large and Macarena during the cropping season, eight irrigations are usually required with an inundation period of 8–12 hours. It is suggested that irrigations be timed to coincide with the following stages of growth:

- pre-sowing irrigation
- post-emergent
- early growth/vegetative
- 50% flowering
- start of podding
- early podding
- mid-podding
- end of podding.

Soil type and seasonal conditions may affect crop growth and development, and consequently, the timing of irrigation at each growth stage. For instance, irrigation may need to be more frequent if temperatures are warmer and when grown on Ord sandy loam, which has a lower water-holding capacity when compared to the Cununurra clay.

The development of root and seedling diseases is promoted by waterlogged conditions at sowing, due to watering too early or excessively following sowing. Therefore, sowing must be delayed until the soil moisture conditions are optimum after the pre-sowing irrigation (14–18 days). Generally, the first post-sowing irrigation is required about 14–18 days after sowing (post-emergence).

Diseases

Seedling diseases and root rots are the most damaging diseases. It is likely that a complex of *Pythium, Fusarium, Phytophthora* and *Rhizoctonia* species causes most diseases. The development of disease can be more severe where the soil remains wet for prolonged periods. Hence, soil moisture at sowing and during crop establishment needs to be monitored to minimise the possibility of waterlogging at this time. It is recommended that seed be treated with P-Pickle T to reduce the risk and impact of disease (see section on Seed Treatment). P-Pickle T is not effective against *Phytophthora* spp.

Crop rotation is important in managing crop disease. Ideally, chickpea rotation needs to be limited to one year in three to minimise the persistence of fungal pathogens in the soil infecting subsequent chickpea crops. Other crops may act as a host for some fungal pathogens (for example other legumes and possibly some other dicotyledons such as cotton), which needs to be considered when selecting paddocks for chickpea. Chickpea following cereal crops such as maize and sorghum produce the best seed yield and quality.

Insects

The main insect pest in the ORIA is heliothis (*Helicoverpa* spp.), which can cause severe damage to crops. If present at flowering and early podding, larvae may feed on flowers and developing pods. Once punctured, seed development ceases in young pods and results in yield loss. During mid to late podding, larvae feed on the developing seeds, causing reduced yields and unmarketable seeds.

Generally, it is not recommended to spray for budworm during the vegetative stage, unless significant damage to the crop is evident (Table 8). Crops need to be checked for budworm twice weekly from the time the crop emerges.

Table 8: *Threshold levels for each developmental stage.*

Growth stage	Threshold (larvae per m of crop)
Vegetative	20–30
Flowering	5
Podding	3 (small-medium) to 5 (very small)

Source: DAFWA

Inter-row cultivation is a cheap and effective method of reducing Helicoverpa levels in chickpea crops, however care is needed to avoid root pruning of the chickpea crop. Cultivation collapses pupal tunnels and prevents the emergence of Helicoverpa moths. Inter-row cultivation can also be useful by reducing weed burden, however pre-sowing weed management is preferred.

Harvest

Approximately two weeks after the final irrigation the crop can be undercut about 2.5 cm below the soil surface. The soil requires some residual moisture to allow effective undercutting. The crop can be harvested between 7 and 14 days after undercutting, depending on weather conditions, crop biomass and crop moisture. The crop is ready to harvest when the stems and pods are light brown and the seed feels hard and rattles within the pod. At this stage, the seed moisture content should be around 15%. Harvesting at lower seed moisture content (13%) increases the susceptibility of the seed to physical damage during and after harvest.

Markets

The Ord River District Co-operative Ltd. markets kabuli chickpea produced in the ORIA. The product mainly supplies domestic markets in Australian capital cities where it is sold as whole seed in specialty shops and, in larger volumes, to hommus, falafel and dip manufacturers. The processing market requires varieties with specific 'after cooking' flavour. Macarena and Kimberley Large varieties provides these quality attributes and are also sold to high value international markets in Italy and surrounding Mediterranean countries. [50]

1.7 Yield and targets

Seed yields of chickpea are low (world average 623 kg/ha^{-1}), compared to many other crops. Early field trials in Merredin, south-western Australia, indicate that seed yield in chickpea is controlled by the Harvest Index of branches and that seed yields might be raised by restricting branches in high density stands to no more than two, each with a high harvest index. [51] Starting soil water can also have a strong influence on the yield expectation of chickpea as well as the riskiness of production.

50 Pritchard I. DAFWA (2014). High value kabuli chickpea production in the Ord River Irrigation Area - post planting guide. https://www.agric.wa.gov.au/chickpeas/high-value-Kabuli-chickpea-production-ord-river-irrigation-area-post-planting-guide

51 K.H.M. Siddique and A.M. Sedgley. An ideotype for chickpea (Cicer Arietinum L.) in a dry mediterranean environment. 2nd Aust. Agron Conf.©,Uni of WA.

Yield results from Pulse Breeding Australia (PBA) and National Variety Trials (NVT) are available from the NVT website as well as from the specific Pulse Variety Management Package (VMP) brochure. Long term yields can be represented in several different ways but are typically displayed as either site specific, averaged over multiple years (Figure 15), or for each year averaged over multiple sites for a region. All trial sites are disease free.

Results lists are estimates for the following varieties (ordered from highest t/ha to lowest) (Figure 16).

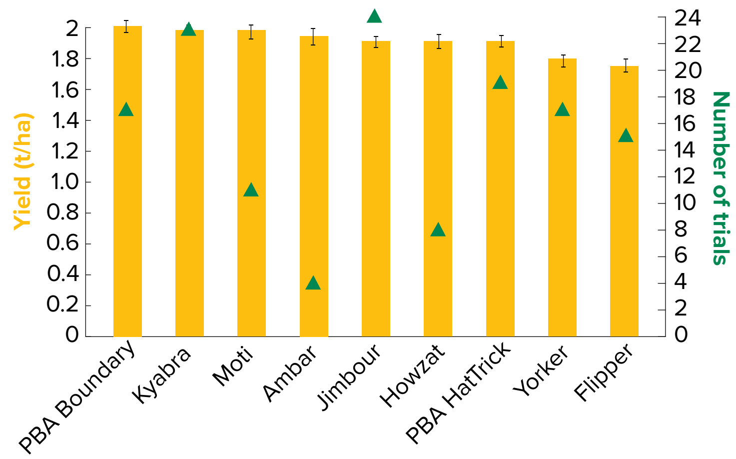

Figure 16: *NVT Long term yield report for desi chickpeas (2005 to 2012).*

Source: GRDC

IN FOCUS

Critical period for chickpea yield

To determine the critical window for chickpea yield, the South Australian Research and Development Institute (SARDI) set up trials at Roseworthy (sowing date 7 June) and Turretfield (sowing dates 14 June and 9 July, 2014) in SA.

Crops of PBA Boundary⚖ and PBA Slasher⚖ were shaded for two weeks at different stages during the growing season. Untreated controls yielded three tonnes per hectare and Figure 19 shows yields achieved by the shade-stressed crops.

The trials showed that the critical window for chickpeas starts at about 300 ‘degree-days’ before flowering and the most vulnerable stage for yield was found to be 200 ‘degree-days’ after flowering (Figure 17).

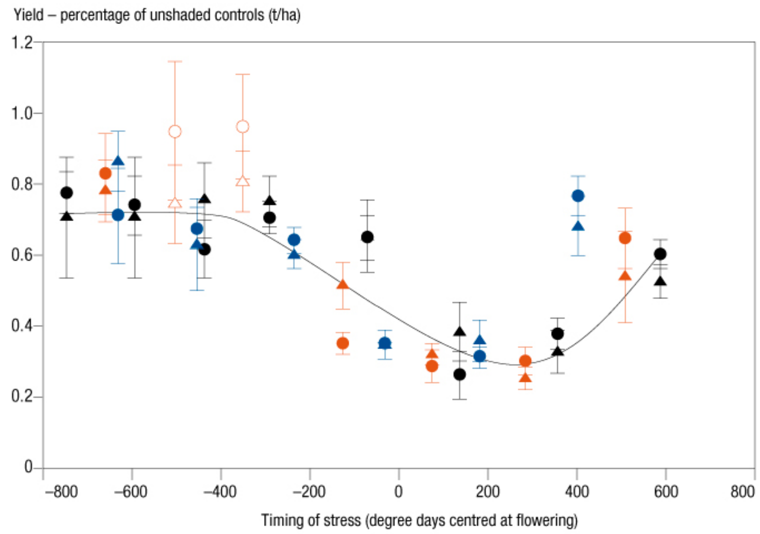

Figure 17: *Yield (percentage of unshaded controls t/ha) of chickpeas in response to timing of stress. PBA Boundary⟮D is represented with circles and PBA Slasher⟮D with triangles. Crops at Roseworthy are shown with black symbols, early-sowing crops at Turretfield are shown in red and late-sowing crops at Turretfield are shown in blue. (Hollow red circles and triangles are not significantly different from the control.) Note: the yield is most severely reduced with stress about 200 to 300 degree days after flowering.*

Source: GRDC

Degree-days are a calculation of time based on daily temperature and are necessary to account for the fact that crops develop faster at high temperatures. For the crop, one day at 15°C is not the same as a day at 10°C.

For example, if chickpeas are grown in conditions where the daily mean temperature is 15°C, the critical stage of 200-degree-days will be reached 13 days after flowering (200 ÷ 15 = 13). If chickpeas are grown in a warmer region or the crop was sown late with, for example, a daily mean temperature of 20°C, the crop will reach the 200-degree-days mark 10 days after flowering (200 ÷ 20 = 10).

Ensuring good growing conditions (sufficient supply of water and nutrients) and avoiding stress (such as frost and heat) during the critical window are essential for high-yielding chickpea crops. [52]

Several tools are available to help growers maximise yields.

Before planting, identify the target yield required to be profitable:

- Do a simple calculation to see how much water you need to achieve this yield.
- Know how much soil water you have (treat this water like money in the bank).
- Think about how much risk your farm can take.
- Consider how this crop fits into your cropping plan, and consider whether the longer-term benefits to the system outweigh any short-term losses.

52 L Lake, V Sandras. SARDI. (Nov – Dec 2014). Ground Cover issue 113: Critical period for chickpea yield. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-113-NovDec-2014/Critical-period-for-chickpea-yield

Avoiding a failed crop saves money now and saves stored water for future crops. [53]

Estimating crop yields

Accurate, early estimation of grain yield is an important skill to have. Farmers require accurate yield estimates for a number of reasons:

- Crop insurance.
- Delivery estimates.
- Planning harvest and storage requirements.
- Cash-flow budgeting.

Extensive personal experience is essential for estimating yield at early stages of growth. As crops near maturity, it becomes easier to estimate yield with greater accuracy.

Estimation methods

There are many methods available for farmers and others to estimate the yield of various crops. Some are straightforward, whereas others are more complicated. The method below can be undertaken relatively quickly and easily. The steps are:

1. Select an area that is representative of the paddock. Using a measuring rod or tape, measure out an area 1 m^2 and count the number of heads or pods.
2. Do this five times to get an average of the crop.
3. Count the number of grains in at least 20 heads or pods, and average.
4. Use a table of grain weights to ascertain the weight you can expect per 100 g for the crop you will plant, the then calculate potential yield.

The accuracy of yield estimates depends on taking an adequate number of counts so as to get a representative average for the paddock. The yield estimate will only be a guide and assumptions made from the estimates contain a degree of uncertainty. This type of yield estimation is one of the easiest and quickest to complete and should be able to be used in a number of situations on a grain-growing property. As grain losses before and during harvest can be significant, factor in an allowance for 5–10% loss in your final calculations. [54]

Yield Prophet

Scientists have aimed to support farmers' capacity to achieve yield potential by developing the Agricultural Production Systems Simulator (APSIM), a model of farming systems that simulates the effects of environmental variables and management decisions on crop yield, profits and ecological outcomes.

Yield Prophet delivers information from APSIM to farmers (and consultants) to aid them in their decision-making. It is an online crop-production model that gives users real-time information about their crops. This tool provides growers with integrated production-risk advice and monitoring decision-support relevant to farm management. By matching crop inputs with potential yield in a given season, by using scenario analysis of different management options, Yield Prophet subscribers may avoid over- or under-investing in their crop. Yield Prophet has enjoyed a measure of acceptance and adoption amongst innovative farmers and has made valuable impacts in terms of assisting farmers to manage climate variability at a paddock level.

The simulations provide a framework for farmers and advisers to:

- forecast yield
- manage climate and soil water risk
- make informed decisions about N and irrigation applications
- match inputs with the yield potential of their crop

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53 J Whish (2013) Impact of stored water on risk and sowing decisions in western NSW. GRDC Update Paper, 23 July 2013. GRDC, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Impact-of-stored-water-on-risk-and-sowing-decisions-in-western-NSW

54 Agriculture Victoria (2015) Estimating crop yields: a brief guide. Note AG1420. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/estimating-crop-yields-a-brief-guide

- assess the effect of changed sowing dates or varieties
- assess the possible effects of climate change

How does it work?

Yield Prophet generates crop simulations that combine the essential components of growing a crop including:

- a soil test sampled prior to planting
- a soil classification selected from the Yield Prophet library of ~1,000 soils, chosen as representative of the production area
- historical and current climate data taken from the nearest Bureau of Meteorology (BOM) weather station
- paddock-specific rainfall data recorded by the user (optional)
- individual crop details
- fertiliser and irrigation applications during the growing season

MORE INFORMATION

Yield Prophet

1.7.1 Seasonal outlook

Australia's climate, and in particular rainfall, is among the most variable on earth; consequently, crop yields vary from season to season. In order to remain profitable, crop producers must manage their agronomy, crop inputs, marketing, and finance to match each season's yield potential.

Mobile applications (apps) are available for decision support, providing tools for ground-truthing precision agriculture data. Apps and mobile devices are making it easier to collect and record data on-farm. The app market for agriculture is evolving rapidly, with new apps becoming available on a regular basis. [55]

The Department of Agriculture and Food, Western Australia (DAFWA) provides up-to-date information about the coming season and its potential impacts on cropping and agriculture. To help make informed on-farm decisions, the DAFWA Seasonal climate information website provides statistical seasonal rainfall forecasts, modelled plant-available soil water at the start of the growing season and risk of frost occurring at different locations.

DAFWA's Season Climate Outlook (SCO) is a monthly newsletter that summarises climate outlooks for the next three months produced by DAFWA's Statistical Seasonal Forecast (SSF) system specifically for the Western Australian wheatbelt, and by the Australian Bureau of Meteorology. It provides a review of recent climate indicators, including ENSO (El Niño Southern Oscillation), the Indian Ocean Dipole, the Southern Annular Mode, as well as local sea surface temperature and pressure systems. At appropriate times of year it also includes an overview of the rainfall outlook for the growing season produced by the SSF. [56]

Australian CliMate

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

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

55 http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Managing-data-on-the-modern-farm

56 DAFWA. Seasonal Climate outlook. https://www.agric.wa.gov.au/newsletters/sco

MORE INFORMATION

GRDC Update paper, Managing data on the modern farm.

since planting. *Season's progress?* provides an objective assessment based on long-term records:

- How is the crop developing compared to previous seasons, based on heat sum?
- Is there any reason why my crop is not doing as well as usual because of below average rainfall or radiation?
- Based on the season's progress, should I adjust inputs?

For inputs, *Season's progress?* asks for the weather variable to be explored (rainfall, average daily temperature, radiation, heat sum with base temperatures of 0, 5, 10, 15 and 20°C), a start month, and a duration. As outputs, text and two graphical presentations are used to show the current season in the context of the average and all years. Departures from the average are shown in a fire-risk chart as the departure from the average in units of standard deviation.

1.7.2 Fallow moisture

For a growing crop there are two sources of water: first, the water stored in the soil during the fallow; and second, the water that falls as rain while the crop is growing. As a farmer, you have some control over the stored soil water; you can measure how much you have before planting the crop. Long-range forecasts and tools such as the SOI can indicate the likelihood of the season being wet or dry; however, they cannot guarantee that rain will fall when you need it. [57]

HowWet/N?

Another CliMate tool, HowWet/N? is a program that uses records from a nearby weather station to estimate how much PAW has accumulated in the soil and the amount of organic N that has been converted to an available nitrate during a fallow. HowWet/N? tracks daily soil moisture, evaporation, run-off and drainage. Accumulation of available N in the soil is calculated based on surface soil moisture, temperature and soil organic carbon.

HowWet/N?:

- Estimates how much rain has been stored as plant-available soil water during the most recent fallow period.
- Estimates the N mineralised as nitrate-N in soil.
- Provides a comparison with previous seasons.

This information aids in the decision about what crop to plant and how much N fertiliser to apply. Many grain growers are in regions where stored soil water and nitrate at planting are important in crop management decisions.

The questions this tool answers are:

- How much longer should I fallow? (If the soil is almost full, maybe the fallow can be shortened.)
- Given my soil type and local rainfall to date, what is the relative soil moisture and nitrate-N accumulation over the fallow period compared with most years? (Relative changes are more reliable than absolute values.)
- Based on estimates of soil water and nitrate-N accumulation over the fallow, what adjustments are needed to the N supply?

Inputs

- A selected soil type and the weather station.
- An estimate of soil cover and starting soil moisture.
- Rainfall data input by the user for the stand-alone version of How Often?

57 J Whish (2013) Impact of stored water on risk and sowing decisions in western NSW. GRDC Update Paper, 23 July 2013. GRDC, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Impact-of-stored-water-on-risk-and-sowing-decisions-in-western-NSW

Outputs

- A graph showing plant-available soil water for the current year and for all other years, and a table summarising the recent fallow water balance.
- A graph showing nitrate accumulation for the current year and all other years.

Reliability

HowWet/N? uses standard water-balance algorithms from HowLeaky? and a simplified nitrate mineralisation based on the original version of HowWet/N? Further calibration is needed before accepting with confidence absolute value estimates.

Soil descriptions are based on generic soil types with standard organic carbon (C) and C:N ratios, and as such should be regarded as indicative only. They are best used as a measure of relative water accumulation and nitrate mineralisation. [58]

MORE INFORMATION

How Wet/N?

1.7.3 Water Use Efficiency

Water Use Efficiency (WUE) is the measure of a cropping system's capacity to convert water into plant biomass or grain. It includes both the use of water stored in the soil and rainfall during the growing season.

Water Use Efficiency relies on:

- the soil's ability to capture and store water;
- the crop's ability to access water stored in the soil and rainfall during the season;
- the crop's ability to convert water into biomass; and
- the crop's ability to convert biomass into grain (harvest index). [59]

The strongest determinant of chickpea grain yield and its water use under rainfed conditions is rainfall and its distribution. Water availability is a major constraint for production of grain in Australia and improving WUE is a primary target for growers, breeders and agronomists. WUE benchmarks can be used to derive attainable yield for a location and season (Table 8).

Table 9: *Effect of planting date on total water use (E_t) and Water Use Efficiency of chickpea at Merredin, WA.* [60]

Planting date	Total water sue (E_t mm)	WUE (kg dry matter ha^{-1} mm^{-1})	GWUF. (kg seed ha^{-1} mm^{-1})	Planting date	Total water use (E_t mm)	WUE (kg dry matter ha^{-1} mm^{-1})	GWUE (kg seed ha^{-1} mm^{-1})
(a) 1982				**(b) 1983**			
11 May (D1)	213.2	23.2	6.81	17 May (D1)	191.8	35.2	6.52
26 May (D2)	214.1	19.5	5.94	31 May (D2)	182.8	29.2	6.18
17 June (D3)	229.6	18.8	5.55	14 June (D3)	182.1	26.6	6.15
30 June (D4)	227.2	16.9	4.86	30 June (D4)	188.3	21.1	5.88
				20 July (D5)	182.1	17.7	5.15
Mean	221.0	19.5	5.79	Mean	185.4	26.2	5.98
l.s.d. (P<0.5)	24.8	2.5	1.09	l.s.d. (P<0.5)	17.8	5.8	1.04
C.V. (%)	7.0	10.2	11.7	C.V. (%)	6.2	12.8	11.3

Seasonality and size of rainfall events also influence crop WUE. In the western and southern growing regions, rainfall is winter-dominant, falling during the crop's growing season and rainfall events are mostly small (< 5 mm). These features of rainfall mean that soil evaporation, favoured by winter rainfall and small events, is the main unproductive source of water loss in western and southern regions. Collectively,

58 Australian CliMate. How Wet/N, http://www.australianclimate.net.au/About/HowWetN

59 GRDC. (2009). Water Use Efficiency – Fact Sheet. Northern Region.

60 Siddique, K. H. M., & Sedgley, R. H. (1987). Canopy development modifies the water economy of chickpea (Cicer arietinum L.) in south-western Australia. Crop and Pasture Science, 37(6), 599–610.

vapour pressure deficit and rainfall patterns are the main climate determinants of location-specific WUE. [61]

Large inter-seasonal fluctuations in weather can result in larger inter-seasonal fluctuations in water use, and therefore in production of legumes. Seasonal evapotranspiration (ET) has been found to significantly correlate with seasonal rainfall for chickpeas.

Potential transpiration efficiencies (TE) of 15 kg/ha–1 mm–1 together with soil evaporation (Es) values of 100–125 mm can be used as benchmark values to assess the yield potential of cool season grain legume crops in low rainfall Mediterranean-type environments. [62]

One study found that a 2/3 supplemental irrigation level gives the optimum WUE for chickpea. [63]

Chickpeas have a relatively short growing season and use less water than many other broadleaf crops such as sunflower or safflower. Chickpeas use less water and thereby leave more water available for succeeding crops. Chickpea has an adaptive root system to drier conditions and large root surface area per unit root weight so can be more tolerant of water deficit stress. [64]

Nitrogen-deficient soils will also reduce WUE, leading to impaired photosynthesis and a drop in above-ground dry matter per unit transpiration.

IN FOCUS

Chickpea Water Use Efficiency in relation to cropping system, cultivar, soil nitrogen and Rhizobial inoculation in semiarid environments

Crops grown in semiarid rainfed conditions are prone to water stress which could be alleviated by improving cultural practices. This study determined the effect of cropping system, cultivar, soil nitrogen status and *Rhizobium* inoculation (*Rz*) on water use and Water Use Efficiency (WUE) of chickpea (*Cicer arietinum* L.) in semi-arid environments. Four varieties were grown in no-till barley, no-till wheat, and tilled-fallow systems and under various rates of N fertiliser (0, 28, 56, 84, and 112 kg N ha–1) coupled with or without *Rz*. On average, chickpea used about 10 mm of water from the top 0–15 cm soil depth. In the tilled-fallow system, chickpea extracted 20% more water in the 15–30 cm depth, 70% more in the 30–60 cm depth, and 156% more in the 60–120 cm depth than when it was grown in the no-till systems. Water Use Efficiency increased from 4.7 to 6.8 kg ha–1 mm–1 as N fertiliser rate was increased from 0 to 112 kg N ha–1 when chickpea was grown in the no-till barley or wheat systems, but chickpea grown in the tilled-fallow system did not respond to changes in the fertiliser N rates averaging WUE of 6.5 kg ha–1 mm–1. In the absence of N fertiliser, the application of *Rz* increased WUE by 33% for chickpea grown in the no-till barley system, 30% in the no-till wheat system, and 9% in the tilled-fallow system. Chickpea inoculated with *Rhizobium* achieved a WUE value similar to the crop fertilised at 84 kg N ha–1. Without the use of *Rz*, chickpea increased WUE in a linear fashion with increasing fertiliser N rates from 0 to 84 kg N ha–1.

61 V Sandras, G McDonald. GRDC. (2012). Water Use Efficiency of grain crops in Australia: principles, benchmarks and management.

62 Siddique, K. H. M., Regan, K. L., Tennant, D., & Thomson, B. D. (2001). Water use and Water Use Efficiency of cool season grain legumes in low rainfall Mediterranean-type environments. European Journal of Agronomy, 15(4), 267–280.

63 Oweis, T., Hachum, A., & Pala, M. (2004). Water Use Efficiency of winter-sown chickpea under supplemental irrigation in a Mediterranean environment. Agricultural water management, 66(2), 163–179.

64 Benjamin, J. G., & Nielsen, D. C. (2006). Water deficit effects on root distribution of soybean, field pea and chickpea. Field Crops Research, 97(2), 248–253.

Cropping system, cultivar, and inoculation all had greater impact on WUE than on the amount of water extracted by the crop from the soil. The improvement of cultural practices to promote general plant health along with the development of cultivars with improved crop yields will be keys for improving Water Use Efficiency of chickpea in semiarid environments. [65]

Crop biomass and grain yield depend on photosynthesis. Photosynthesis involves the uptake of carbon dioxide (CO_2) through stomata, which are pore-like, specialised cells in the surface of leaves. However, open stomata required for CO_2 uptake are an open gate for water loss. Therefore, there is a tight trade-off between uptake of CO_2 and water loss, and this explains the close link between crop production and water use. [66]

Managing to optimise Water Use Efficiency

Measures to improve WUE should aim to reduce soil evaporation during winter both directly – e.g. by increasing soil cover, by mulches or earlier-developing canopies – and indirectly, by increasing infiltration. In spring, measures to increase WUE should aim to reduce transpiration by minimising canopy development to what is required by the crop to maximize harvest index. [67]

Although farmers have no control over rainfall, by using different management practices they can affect how much of the rainfall is used by the crop and how efficiently it is used.

Fallowing captures out-of-season rainfall and can increase the amount of water available for crop growth. However, the proportion of rainfall retained by fallowing (also referred to as fallow efficiency) can be small, typically in the order of 20% but often less.

Retaining stubbles on the fallow and controlling summer weeds may help to reduce water loss from the fallow and improve fallow efficiency, although the value of stubble retention appears to vary with soil texture and rainfall. On sandy soils, there may be little benefit from stubble retention on water capture over summer, and in some cases standing stubble may increase evaporative losses. In contrast, on clay soils in southern Australia, fallow efficiencies up to 40% have been measured with retained stubbles.

Crop choice: There are differences in WUE between crops, with wheat having higher WUE than grain legumes or canola. Chickpeas in WA have been estimated to have a WUE based on total biomass of 16.0 (11.1–18.3) kg/ha.mm and based on grain yield of 6.2 (4.7–8.9) kg/ha.mm. [68]

Arguably, time of sowing is the most important management practice determining WUE and yield. Many studies in a range of crops have shown that 'late' sowing will reduce yields, although for short-season varieties, sowing very early may have little benefit or may reduce yields. Time of sowing generally has only a small effect on total crop water use but can have a marked effect on WUE. The highest water use efficiencies are consistently achieved when the crop is sown at the optimum time. Late sowing reduces WUE for a number of reasons: sowing into colder soil delays crop establishment and early vigour, which increases the proportion of crop evapotranspiration lost as soil evaporation; there is a higher likelihood of heat stress around flowering and during grain growth; and there are reductions in biomass per unit water use associated with increasing vapour pressure deficit.

65 Gan, Y. T., Warkentin, T. D., Bing, D. J., Stevenson, F. C., & McDonald, C. L. (2010). Chickpea Water Use Efficiency in relation to cropping system, cultivar, soil nitrogen and Rhizobial inoculation in semiarid environments. Agricultural water management, 97(9), 1375–1381.

66 V Sandras, G McDonald. GRDC. (2012). Water Use Efficiency of grain crops in Australia: principles, benchmarks and management.

67 Siddique, K. H. M., & Sedgley, R. H. (1987). Canopy development modifies the water economy of chickpea (Cicer arietinum L.) in south-western Australia. Crop and Pasture Science, 37(6), 599–610.

68 Siddique, K. H. M., Regan, K. L., Tennant, D., & Thomson, B. D. (2001). Water use and Water Use Efficiency of cool season grain legumes in low rainfall Mediterranean-type environments. European Journal of Agronomy, 15(4), 267–280.

The spatial arrangement of plants in crops, the result of the chosen row spacing and sowing rate, affects crop water use in two main ways: first, it affects the rate of early growth and the degree and timing of canopy closure, and thus the proportion of crop water use lost as soil evaporation; and second, it influences the partitioning of water use between the pre-anthesis and post-anthesis periods. The amount and distribution of rainfall will largely influence the optimum sowing rate. Nevertheless, grain yields (and WUE) are quite stable over a wide range of sowing rates, which affords a degree of flexibility when deciding on the most appropriate sowing rate. Increased sowing rates increase early crop growth rate and potentially reduce evaporation from the soil surface thus 'saving' water for use later in the season.

On the other hand, high sowing rates will lead to vigorous early crop growth and water use which may cause early depletion of soil moisture if rainfall is low. In general, using low plant densities in low-rainfall regions, or in regions where crops depend on soil moisture reserves at sowing, helps to partition water use between the pre-flowering and post-flowering periods more effectively. Row spacing may have relatively little effect on WUE. The potential gains in WUE from altering row spacing will depend on how it affects the proportion of moisture lost from bare soil evaporation and how it influences the pattern of water use during the growing season. Increased row spacing can lead to increased exposure of the soil surface and raised soil evaporation, but where the maximum leaf area of the crop is small, or where the soil surface is not moist for long periods of time, altering row width has little effect on bare soil evaporation. Present evidence suggests that using wide rows in non-cereal crops may have limited benefit to the efficient use of seasonal rainfall or may cause reductions in efficiency. [69]

WATCH: Over the Fence West: Max soil water with plastic.

69 V Sandras, G McDonald. GRDC. (2012). Water Use Efficiency of grain crops in Australia: principles, benchmarks and management.

MORE INFORMATION

[Water Use Efficiency of grain crops in Australia: principles, benchmarks and management]

WATCH: GCTV12: Water Use Efficiency Initiative

1.7.4 Nitrogen use efficiency

Over 40 years, the amount of mineral N fertilisers applied to agricultural crops increased 7.4 fold, whereas the overall yield increase was only 2.4 fold. This means that N use efficiency, (NUE) which may be defined as the yield obtained per unit of available N in the soil (supplied by the soil + N fertiliser) has declined sharply. NUE is the product of absorption efficiency (amount of absorbed N/quantity of available N) and the utilisation efficiency (yield/absorbed N). For a large number of crops, there is a genetic variability for both N absorption efficiency and for N utilisation efficiency. [70]

Breeding for more efficient symbioses with *Rhizobia* and *Arbuscular micorrhizal* (AM) fungi can be an alternative for increasing plant productivity using the same amount of synthetic N fertiliser. Conservation tillage using no-till and continuous cover cropping cultures are also known to increase significantly the potentiality and diversity of plant colonisation by AM fungi in comparison to conventional tillage. Thus, these new alternative farming techniques can increase NUE for a number of crops through the beneficial action of AM.

Under both, humid conditions and dry weather chickpea has been found to maintain a constant partial factor N use efficiency (PFNUE: grain yield per unit fertiliser N) and a consistently high N utilisation efficiency (NUE: grain yield per unit N in the above-ground dry matter) for grain production. [71]

Whatever the mode of N fertilisation, an increased knowledge of the mechanisms controlling plant N economy is essential for improving NUE and for reducing excessive input of fertilisers, while maintaining an acceptable yield and sufficient profit margin for farmers.

1.7.5 Double crop options

Double cropping is growing a winter and summer crop following one another. Chickpeas are a very good crop to double crop out of an early sorghum crop straight back into chickpea, avoiding the need for long fallow in wet summers. This is possible because chickpea needs less water than wheat, depending on what yield a grower is targeting.

70 Hirel, B., Tétu, T., Lea, P. J., & Dubois, F. (2011). Improving nitrogen use efficiency in crops for sustainable agriculture. Sustainability, 3(9), 1452–1485.

71 Neugschwandtner, R. W., Wagentristl, H., & Kaul, H. P. (2015). Nitrogen yield and nitrogen use of chickpea compared to pea, barley and oat in Central Europe. International Journal of Plant Production, 9(2), 291–304.

IN FOCUS

Strategic double cropping on Vertisols: A viable rainfed cropping option in India to increase productivity and reduce risk

A long-term (15 year) experiment in India demonstrated that cropping during the rainy season is feasible, and that grain productivity of double cropped sorghum + chickpea (SCP–SCP) and mung bean + sorghum (MS–MS) sequential systems were higher than their conventional counterparts with rainy season fallow; i.e. fallow + post-rainy sorghum (FS–FS) and fallow + post-rainy chickpea (FS–FCP). In the SCP–SCP system the additional grain yield of rainy sorghum (3400 kg ha–1 per two-year rotation) ensured that the total productivity of this system was greater than all other systems. Double cropping MS–MS and SCP–SCP sequential systems had significantly higher crop N uptake compared to traditional fallow systems at all rates of applied nitrogen(N). The intensified MS–MS and SCP–SCP sequential systems without any N fertiliser applied recorded a much higher median gross profit. Applying 120 kg of N ha–1 considerably increased the profitability of all systems. The gross profit margin analysis showed that nitrogen is a key input for improving productivity, particularly for the double cropping systems. However, traditional systems are unviable and risky without N application in the variable climates of the semi-arid tropics. Together, our results show that on Vertisols in semi-arid India, double cropping systems increase systems' productivity, and are financially more profitability and less risky than traditional fallow post-rainy systems while further benefits can be achieved through fertiliser application. [72]

1.8 Disease status of paddock

Three pre-planting practices are paramount for managing chickpea diseases: stubble management, controlling volunteers and weeds, and paddock selection.

Floods and surface water flows can distribute inoculum of *Phoma rabiei* (formerly *Ascochyta rabiei*, causing ascochyta blight) and *Botrytis cinerea* (causing botrytis grey mould) as well as *Sclerotinia*, *Phytophthora root rot* and root-lesion nematodes across large areas of the northern region cropping belt. Some diseases such as ascochyta blight are considered 'community diseases', so what happens in a neighbouring paddock or even several kilometres away can affect crops. [73]

Ascochyta blight in chickpeas is now manageable, but can still loom as the biggest potential issue in Australian chickpea production unless it is managed by a combination of variety choice, strategic use of fungicides and crop hygiene (seed source, rotation, proximity of chickpea stubbles).

Chickpea crops in southern Australia and isolated parts of northern Australia are being hit by a more virulent strain of the damaging ascochyta blight. Pulse pathologists in Victoria and South Australia have noted a marked decline in the resistance of several varieties of chickpeas, with varieties previously rated as

72 Rao, V. N., Meinke, H., Craufurd, P. Q., Parsons, D., Kropff, M. J., Anten, N. P., ... & Rego, T. J. (2015). Strategic double cropping on Vertisols: A viable rainfed cropping option in the Indian SAT to increase productivity and reduce risk. European Journal of Agronomy, 62, 26-37.

73 GRDC (2011) What to consider before planting chickpeas. GRDC Media Centre 6 June 2011

moderately resistant performing like susceptible lines. [74] There have been no reported cases of this new Ascochyta blight strain in Western Australia.

Ascochyta resistant varieties are not immune to ascochyta blight, particularly at pod fill, but do make it easier to control with reduced risk, inputs and expense. Lower rainfall areas must be considered as being at least medium risk for ascochyta, but could be high risk on an individual paddock basis. Know the ascochyta blight disease rating of the variety grown; assess the individual paddock risk and manage the crop appropriately. Be aware of the specific management needs for the variety chosen through its variety management package (VMP).

Avoid sowing chickpeas into paddocks that have a recent and prolonged history of predominantly legume (e.g. medic, lentil, and field pea) or broadleaf crops (e.g. canola). *Phoma, Fusarium, Pythium or Sclerotinia* may be present.

Seed treatment should be considered mandatory for protection, especially with kabuli types. Resistance to PRR may perhaps provide slightly better tolerance to waterlogging or common root rots. [75]

1.8.1 Cropping history effects

Paddocks closer than 1 km to last year's chickpea stubble should be considered as a higher risk from ascochyta blight infection and need to be managed as such. Varieties with higher ascochyta resistance such as PBA Slasher⚲, GenesisTM090 or GenesisTM509 should be considered, otherwise there is the need for programmed ascochyta spraying through the season. Where possible, place as great a distance as practicable between this year and last year's chickpea paddocks and be mindful of common wind direction. [76]

For more information, see Section 9: Diseases.

1.9 Nematode status of paddock

Root lesion nematodes (RLN) are widespread in cropping soils through WA. Although mainly considered an issue in wheat crops, RLN also infects chickpeas, with yield losses of 20–30% previously recorded in intolerant varieties. Chickpeas are susceptible to RLN which means that this nematode colonises the root systems and builds up numbers in the soil. However, chickpea varieties can vary in their levels of resistance to RLN; this is related to the extent to which they build up RLN populations in the soil, which then dictates the effect on subsequent crops in the rotation. Varieties that are more susceptible allow greater multiplication of RLN in their root systems over a season. The higher the resulting RLN population left in the soil following chickpeas, the greater is the potential for a negative impact on the yield of subsequent crops.

1.9.1 Effects of cropping history on nematode status

Root-lesion nematode numbers build up steadily under susceptible crops and cause decreasing yields over several years. Yield losses >50% can occur in some wheat varieties, and up to 20% in some chickpea varieties. The amount of damage caused will depend on:

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

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

74 Heard G. (2016). Ascochyta pressure on chickpeas http://www.stockandland.com.au/story/4085979/ascochyta-pressure-on-chickpeas/

75 Pulse Australia. Southern Pulse Bulletin PA 2010 #05 – Chickpea checklist for southern growers. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-checklist-south.pdf

76 Pulse Australia. Southern Pulse Bulletin PA 2010 #05 – Chickpea checklist for southern growers. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-checklist-south.pdf

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

Growing resistant crops is the main tool for managing nematodes. In the case of crops such as chickpea, choose the most tolerant variety available and rotate with resistant crops to keep nematode numbers at low levels. Information on the responses of crop varieties to RLN is regularly updated in grower and planting guides. Note that crops and varieties have different levels of tolerance and resistance to different nematode species.

Summer crops have an important role in management of RLN. Research shows when RLN is present in high numbers, two or more resistant crops in sequence are needed to reduce populations to low enough levels to avoid yield loss in the following intolerant, susceptible crops. [77]

For more information, see Section 8: Nematodes.

1.10 Testing soil for disease and nematodes

MORE INFORMATION

Root lesion nematode has a picnic in 2013, 2014 Crop Updates paper

Pratylenchus teres - WA's home grown Root Lesion Nematode, 2013 Crop Updates paper

Root lesion and burrowing nematodes: diagnosis and management.

Diseases and nematodes that occur underground can be difficult to detect and diagnose but they must be identified correctly to enable appropriate control measures to be implemented. It is important to have paddocks diagnosed for plant parasitic nematodes and disease so that optimal management strategies can be implemented. Testing your farm will tell you if nematodes or disease are present in your paddocks and at what density as well as which species are present.

It is important to know which species are present because some crop-management options are species-specific. If a particular species is present in high numbers, immediate decisions must be made to avoid losses in the next crop to be grown. With low numbers, it is important to take decisions to safeguard future crops. Learning that a paddock is free of these nematodes is valuable information because steps may be taken to avoid its future contamination.

Testing of soil samples taken either before a crop is sown or while the crop is in the ground provides valuable information. There is a great deal of spatial variation in nematode populations within paddocks. It is critical to follow sampling guidelines to ensure accurate results. [78]

It is crucial that diseases are correctly diagnosed to enable the right control measures to be employed for the benefit of crop yields.

1.10.1 Soil and plant testing services for diagnosing root diseases

MORE INFORMATION

MyCrop app

First, look at the distribution of symptomatic plants throughout the whole crop

To determine whether a fungal or nematode root disease is present in a crop, look for patchy areas of poor crop development associated with localised disease build-up. Some root disease may be more evenly scattered or distributed throughout the crop.

Next, carefully dig up samples of apparently diseased as well as healthy plants.

Thoroughly wash the soil from the roots and examine them for indicative symptoms which vary to some extent depending on the disease. Unthrifty plants may have smaller root mass, fewer root branches, root browning, root clumping or damaged root tips (spear tips) compared to thrifty or well-grown plants nearby.

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

78 S Simpfendorfer, M Gardner, G McMullen (2013) Desi chickpea varieties differ in their resistance to the root lesion nematode Pratylenchus thornei—Come-by-Chance 2010. Northern Grains Region Trial Results, autumn 2013. pp. 114–116. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/468328/Northern-grains-region-trial-results-autumn-2013.pdf

Confirmation of diagnosis

Suspected root disease or nematode problems in-crop can be confirmed by laboratory analysis of soil and/or roots. For patch diseases, sample from the edge of the patch rather than the centre.

Do not send washed plants to the laboratory. Follow sampling guidelines from DDLS Seed Testing and Certification.

Growing season tests are carried out on affected plants and associated soil. Although little can be done during the growing season to correct a fungal or nematode root disease, it is important to identify the cause of the problem so that decisions on appropriate management strategies can be taken leading up to and during the following seasons. Test kits are available from DDLS and participating distributors. To obtain submission forms and full sampling instructions, contact your local DAFWA office. Information can also be found online or by phoning +61 (0)8 9368 3721.

Pre-season assessment: the risk of root diseases being present in a paddock at a yield-limiting level next season can be determined by paddock history, paddock monitoring in spring or soil tests. A review of paddock history will identify the diseases likely to be present in each paddock. The level of disease likely to develop can be determined by digging up plants in spring from areas of poor growth and examining the roots for symptoms.

An informed decision can be made about the future use of each paddock based on the presence or absence of a disease and the conduciveness of the current season and crop to further develop that disease.

Pre-season soil tests can be used where the paddock history is not adequate for planning future use. Soil tests are conducted on representative soil samples. PreDicta-B™ uses DNA assessment to determine the root diseases or nematode species present and the likely risk of crop damage. Test kits are available through accredited agronomists and resellers. [79]

PreDicta B (B = broadacre) is a DNA-based soil testing service to identify which soilborne pathogens pose a significant risk to broadacre crops prior to seeding (Figure 17).

It has been developed for cropping regions in Australia and includes tests for:

- cereal cyst nematode (CCN)
- take-all (*Gaeumannomyces graminis* var. *tritici* (Ggt) and G. *graminis* var. *avenae* (Gga))
- rhizoctonia barepatch (Rhizoctonia solani AG8)
- crown rot (*Fusarium pseudograminearum*) * Note that oats are not very susceptible to crown rot – but does host it.
- root lesion nematode (*Pratylenchus neglectus* and *P. thornei*)
- stem nematode (*Ditylenchus dipsaci*)

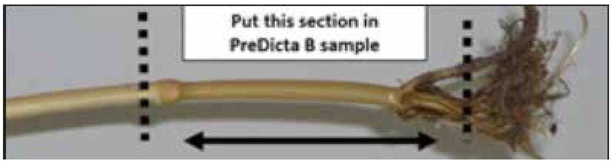


Figure 18: *Correct sampling strategy.*

Source: GRDC

PreDicta B samples are processed weekly from February to mid-May (prior to crops being sown) to assist with planning the cropping program. PreDicta B is not intended for in-crop diagnosis. That is best achieved by sending samples of affected plants to your local plant pathology laboratory.

79 DAFWA (2016). Root disease under intensive cereal production systems. https://www.agric.wa.gov.au/barley/root-disease-under-intensive-cereal-production-systems

See the PIR SA Predicta B website for more information.

1.11 Insect status of paddock

Deciding the best way to sample for a particular pest depends on where in the crop the pest feeds and shelters, and the effects of weather on its behaviour. The stage of crop development and the insect being monitored, will determine which sampling method is most suitable. For example, pests in seedling crops generally cannot be collected by sweeping because the crop is too short.

Pest outbreaks occur often in response to natural conditions, but sometimes in response to management practices. Minimum tillage and stubble retention have resulted in greater diversity of invertebrate species seen in crops. Cultural control methods such as burning, rolling or cultivating stubbles are sometimes needed to compliment chemical and biological controls. [80]

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

Soil insects include:

- cockroaches
- crickets
- earwigs
- black scarab beetles
- cutworms
- false wireworm
- true wireworm

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

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

Soil insect control measures are normally applied at sowing. Since different insects require different control measures, the species of soil insects must be identified before planting. Soil insects are often difficult to detect as they hide under trash or in the soil. Immature insects such as false wireworm larvae are usually found at the moist/dry soil interface.

1.11.1 Insect sampling of soil

Sampling methods should be applied in a consistent manner between paddocks and sampling occasions. Any differences can then be confidently attributed to changes in the insect populations, and not different sampling techniques.

The majority of crop monitoring for insect pests is done with a sweep net, or visually. Using a shake/beating tray is another technique. Sampling pastures mostly relies on visual assessment of the sward or the soil below it. The sweep net is the most convenient sampling technique for many insects. The net should be about 38 cm in

80 https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Emerging-insect-pests

diameter, and swept in a 180 arc from one side of the sweepers body to the other. The net should pass through the crop on such an angle that it is tilted so that the lower lip travels through the crop marginally before the upper lip. The standard sample is 10 sweeps, taken over 10 paces. This sampling set should be repeated as many times as practicable across the crop, and at no less than five locations. After completing the sets of sweeps, counts should be averaged to give an overall estimate of abundance. Sweep nets tend to under-estimate the size of the pest population. Sweep net efficiency is significantly affected by temperature, relative humidity, crop height, wind speed, plant density and the operator's vigour. [81]

Soil sampling by spade

1. Take a number of spade samples from random locations across the field.
2. Check that all spade samples are deep enough to take in the moist soil layer (this is essential).
3. Hand-sort samples to determine type and number of soil insects.

Germinating-seed bait technique

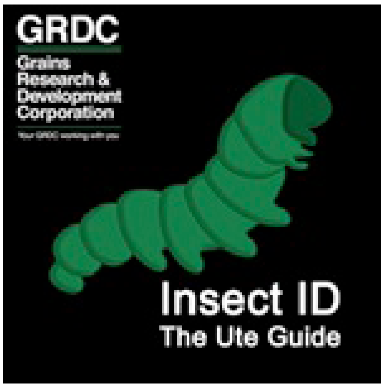
Immediately following planting rain:

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

Trials have shown no difference in the type of seed used for attracting soil-dwelling insects. However, use of the type of seed to be sown as a crop is likely to indicate the species of pests that could damage that crop. The major disadvantage of the germinating-grain bait method is the delay between the seed placement and assessment. [82]

The South Australian Research and Development Institute (SARDI) Entomology Unit provides an insect identification and advisory service. The unit identifies insects to the highest taxonomic level for species where this is possible and can also give farmers biological information and guidelines for control. [83]

Insect ID: The Ute Guide



The Insect ID Ute Guide is a comprehensive reference guide for insect pests commonly affecting broadacre crops and growers across Australia, and includes the beneficial insects that may help to control them. Photos have been provided for multiple life-cycle stages, and each insect is described in detail, with information on

81 http://ipmguidelinesforgrains.com.au/insectopedia/introduction/sampling.htm

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

83 http://pir.sa.gov.au/research/research_specialties/sustainable_systems/entomology/insect_diagnostic_service

MORE INFORMATION

Pest Genie Australia

APVMA.

the crops they attack, how they can be monitored and other pests that they may be confused with. Use of this app should result in better management of pests, increased farm profitability and improved chemical usage. [84]

App Features:

- Region selection
- Predictive search by common and scientific names
- Compare photos of insects side by side with insects in the app
- Identify beneficial predators and parasites of insect pests
- Opt to download content updates in-app to ensure you're aware of the latest pests affecting crops for each region
- Ensure awareness of international bio-security pests

Insect ID, The Ute Guide is available on Android and iPhone.

For more information see Section 7: Insect control

1.11.2 Effect of cropping history

It is important to consider paddock history when planning for pest management. Resident pests can be easier to predict by using paddock history, and agronomic and weather data to determine the likely presence (and numbers) of certain pests within a paddock. This will point towards the likely pest issues and allow growers to implement preventive options. [85] Reduced tillage and increased stubble retention have changed the cropping landscape with respect to soil moisture retention, groundcover and soil biology and this has also affected the abundance and types of invertebrate species being seen in crops. These systems increase invertebrate biodiversity but also create more favourable conditions for many pests such as slugs, earwigs, weevils, beetles and many caterpillars. In turn they have also influenced beneficial species such as carabid and lady beetles, hoverflies and parasitic wasps. [86]

See Section 7: Insect control for more information.

84 https://grdc.com.au/Resources/Apps

85 https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-117-July-August-2015/Growers-chase-pest-control-answers

86 https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Emerging-insect-pests