Optimising
Irrigated Grains

GRDC
GRAINS RESEARCH
& DEVELOPMENT
CORPORATION

FAR
AUSTRALIA

Irrigated Cropping Council
Promoting irrigated agriculture

GOOD MANAGEMENT GUIDELINES
Irrigated Crops

2020 to 2022

Good Management Guidelines for Irrigated Crops

Contents

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BACKGROUND

What was the aim of the project?

This GRDC investment Optimising Irrigated Grains (OIG) (FAR1906-003RTX) was set up to identify gaps in our knowledge regarding the true economically attainable yield potential of winter and summer crops grown in southeastern Australian irrigated farming systems. The focus was on crops where there was less knowledge of upper end yield potential, particularly in light of newer germplasm, management advances and innovations in soil amelioration, as well as evaluating crop suitability for specific irrigated regions.

What did we do?

The project team (FAR Australia and Irrigated Cropping Council (ICC)) was charged with conducting over 60 individual trials per annum, in six crops, over a three-year research period (2020 – 2022). To conduct such a large number of trials, field experiments were consolidated into two major Irrigated Research Centres (IRCs) based at Kerang in Victoria and Finley in southern NSW. Most trials focussed on crop agronomy and were conducted on a grey clay soil at Kerang using predominately surface irrigation (flood), and at Finley on a red duplex using overhead and surface irrigation in collaboration with Southern Growers, NSW DPI and the Maize Association of Australia. Three satellite sites carried a smaller number of trials in the north midlands of Tasmania, south-eastern Australia and Griffiths in NSW in collaboration with Irrigation Research and Extension Committee (IREC), Riverine Plains Inc, Southern Farming Systems, South Australian Research and Development Institute (SARDI) and MacKillop Farm Management Group.

The research programmes were uniquely developed to evaluate crop specific agronomic management practices in irrigated environments in order to ascertain their effects on system productivity and profitability.

Crop specific agronomic practices were focussed on maximising system profitability through:

1. Understanding the yield potential of irrigated crops in the principal environments where research was taking place.
2. Understanding how to consistently optimise yield for the crops where gaps in knowledge were most apparent.
3. Optimising the return on nitrogen through improved nitrogen use efficiency (grain maize, canola, barley and durum).

Linking with the NSW DPI soils team led by Dr Ehsan Tavakkoli, the project team also focussed on evaluating the effectiveness of novel soil management technologies aimed at improving soil structure, infiltration and moisture retention in irrigated farming systems. This soil amelioration research took the form of two trials set up in March 2020 on (i) shallow and poorly structured red duplex soils – Finley, NSW and (ii) sodic grey clays prone to dispersion and waterlogging at Kerang, VIC.

Which crops?

The crops researched as part of the project were:

i) Faba bean (the pulse crop seen with the most potential for irrigated systems), ii) chickpea (an emerging high value pulse, important in crop sequences to provide a cereal disease break), iii) durum (the major option to increase the profitability of the cereal phase under irrigation), iv) canola (higher yields provide scope for significant increases in profitability and potential break effect) and v) **grain maize (the summer crop seen as the crop with the greatest scope to improve returns under a double cropping system).**

In tendering for the project, the project team added a sixth crop which was barley. This was based on spring sown barley in Tasmania and testing winter barley germplasm where appropriate on the mainland.

Wheat agronomy was not a focus of the work in this project, with the exception of a small amount of trial activity in southeast South Australia.

1. Introduction

The guidelines and results set out in this booklet are the result of research taking place across three seasons (2020 – 2022) with mostly la Nina weather patterns. As a result, the cropping years of the project were subject to cooler more mild spring temperatures, ideally geared for the project team to explore the upper range of yield potential for the crops tested. Although spring temperatures were mild, rainfall patterns across the three seasons were very different, with as much rainfall in October 2022 as what fell in the whole growing season of 2020 at the Finley site: Kerang also experiencing a growing season rainfall (GSR) of decile 2, 6 and 10 over the three years of the project. In many ways, the weather patterns in 2022 did not allow the evaluation of irrigated crops since after initial early spring applications no further irrigation was required.

It is important that we recognise these guidelines have been based on three relatively mild seasons compared to the three years previous (2017 – 2019) when weather patterns were vastly different. With growing conditions ideally suited to generate higher yields in 2020 and 2021, it was an ideal opportunity for the project team to evaluate the upper end of yield potential and the inputs that support those yields; however, it comes with caveats when compared to seasons with higher spring temperatures and higher water prices. The differences in temperature, solar radiation and rainfall over these two three-year periods (2017-19 versus 2020 – 2022) are contrasted in the figure below for our principal research sites at Finley and Kerang.

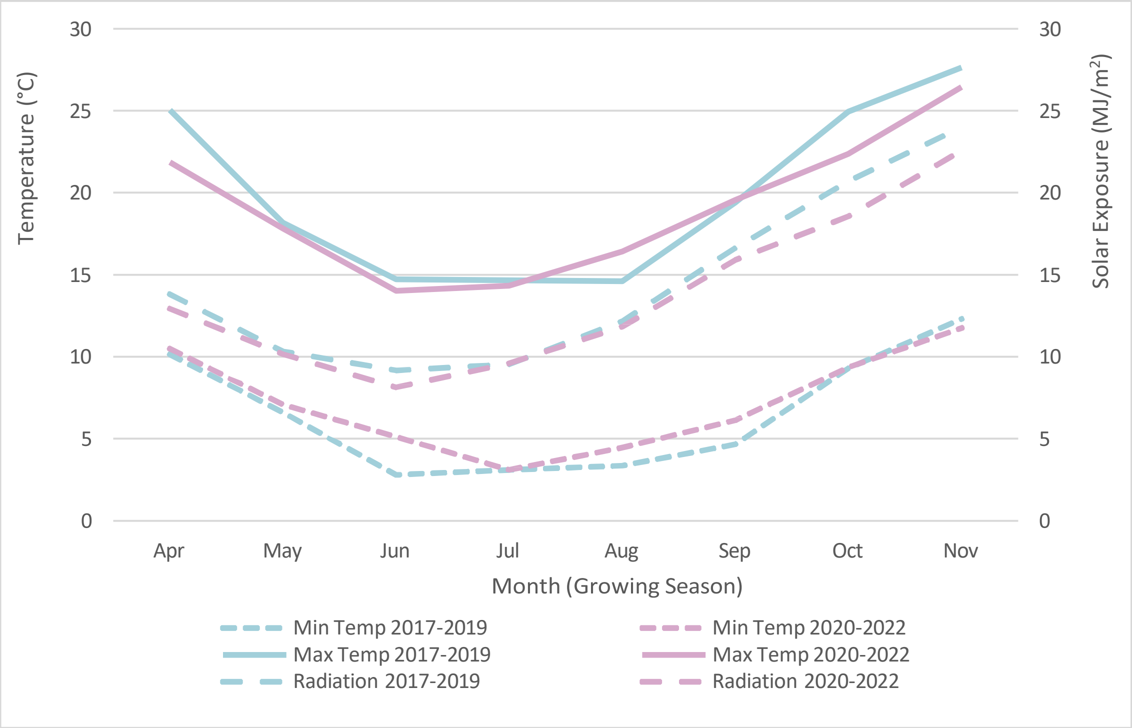


Figure 1. *Contrasts of temperatures, solar exposure (radiation) 2017 – 2019 vs 2020 – 2022. Finley, NSW.*

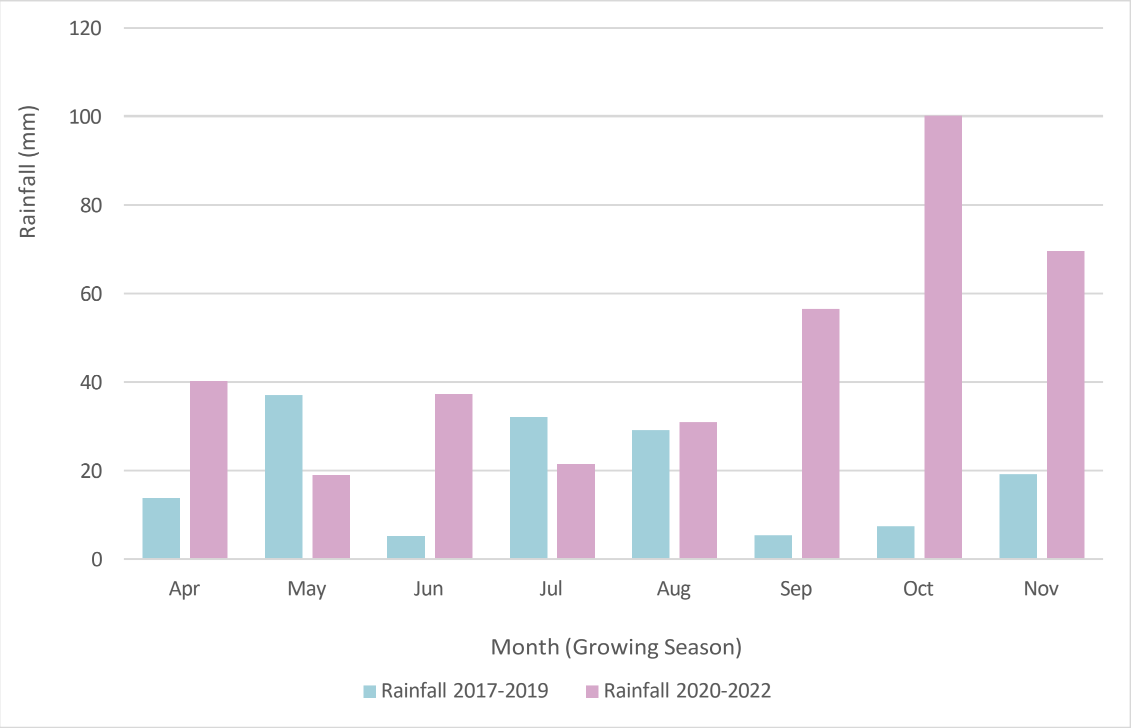


Figure 2. *Contrast of rainfall (need for irrigation) 2017 – 2019 vs. 2020 – 2022. Finley, NSW.*

Over the three years of the project, growing season rainfall at Finley averaged 306mm, contrasted with the previous three years where GSR averaged 130mm – less than half. Of note is that rainfall was much lower in the spring in 2017-19 and subsequently the need for irrigation was higher. Solar radiation in September/October, the critical period for setting potential grain/seed number and seed set, was lower in 2020-22 than 2017-19, however maximum temperatures were also lower. The ratio between average daily temperature and solar radiation was the same for both periods, thus yield potential as determined by Photothermal Quotient (PTQ) was the similar (assuming with irrigation soil moisture was not limited (see section 2.1).

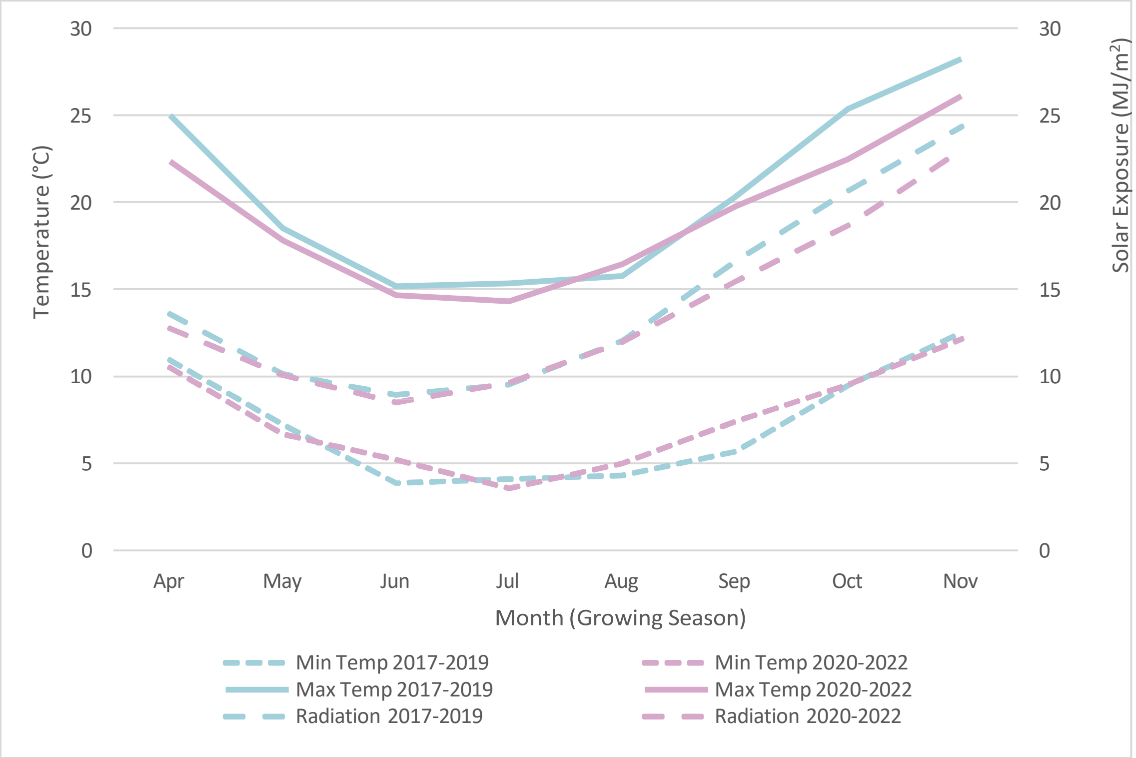


Figure 3. *Contrasts of temperatures, solar exposure (radiation) 2017 – 2019 vs 2020 – 2022. Kerang, Vic.*

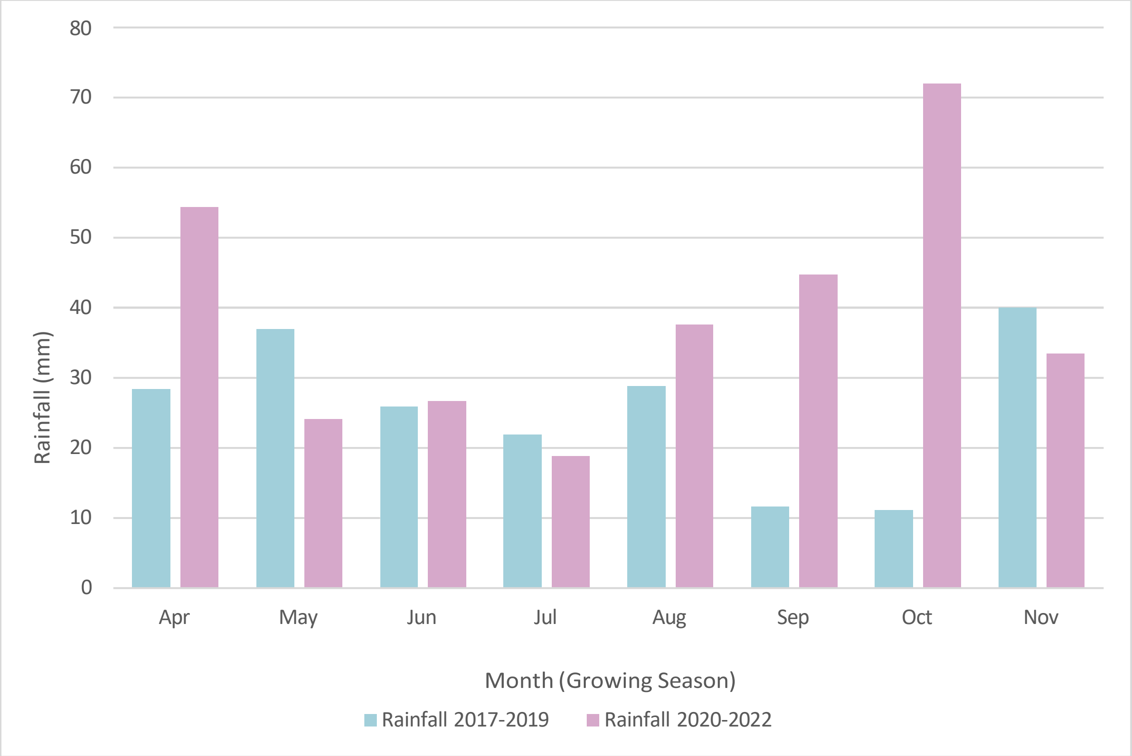


Figure 4. *Contrast of rainfall (need for irrigation) 2017 – 2019 vs. 2020 – 2022. Kerang, Vic.*

Over the three years of the project growing season rainfall at Kerang averaged 278mm, contrasted with the previous three years where GSR averaged 165mm. Rainfall was much lower in the spring in 2017-19 and subsequently the need for irrigation was higher. Solar radiation in September/October, the critical period for seed site formation was lower in 2020-22 than 2017-19 however maximum temperatures were also lower.

The following 'Good Management Guidelines for Irrigated Crops' are based on the general principles and considerations when growing irrigated crops in association with research summaries drawn from experiments conducted over the three seasons.

To look at the aspirational yields that might be achieved by growers using irrigation, we have been assisted by the University of Tasmania (UTAS) team that have been looking after the economics and modelling components of the project. UTAS kindly provided us aspirational yield potentials for research site regions using the APSIM modelling platform (see section 2.2).

2. General principles for the management of irrigated crops

2.1 Yield potential of irrigated crops

There is a common misconception that yield potential in comparison to dryland cropping is freed from physiological constraints as soon as irrigation water is added, and available soil moisture is no longer a limiting factor. This is not the case as it ignores two fundamental considerations that are extremely important in estimating irrigated yield potential. These two factors are temperature and solar radiation which when combined can estimate yield potential in both dryland and irrigated crops. This relationship is referred to as Photothermal Quotient (PTQ = radiation/temperature) or as it is sometimes referred to the Cool Sunny Index. Put simply this relationship shows that cooler temperatures and sunnier conditions (daylength and cloud free skies) during grain/seed number formation (referred to as the critical period) leads to greater growth (photosynthesis), and as a result, more potential grain sites and thus higher yield potential. A higher PTQ can result from both higher radiation and lower temperatures; for example, in 2021 many regions experienced higher solar radiation than that experienced in the same period in 2022, leading to higher yield potential in 2021 than in 2022. Note that use of PTQ to estimate yield potential assumes that there are no other stresses influencing yield potential, such as soil water stress, frost, nutritional or other stress (pests and diseases) that would constrain growth given the specific conditions of light and temperature.

Adding irrigation water does not free us from the constraint of heat and reduced solar radiation.
So, what did PTQ tell us about the yield potential of irrigated cereal crops grown in 2020, 2021 and 2022? The relationship has been most studied on cereal crops, therefore the following estimation of potential yields looks at wheat, although more research is now taking place on additional crops such as canola and pulses to further define critical periods.

Table 1. *Estimated yield potential of wheat at the Irrigated Research Centres over the three project years. (*Note potential yields assume no other stress factors).*

Location	Estimated Optimum flowering date	Calculated PTQ (MJ/m2/d/oC>0)			Potential Yield based on PTQ (t/ha)*		
		2020	2021	2022	2020	2021	2022
Finley, NSW	18-Oct	1.23	1.33	1.16	11.1	11.9	10.4
Kerang, VIC	13-Oct	1.13	1.28	1.16	10.1	11.5	10.4
Frances, SA	27-Oct	1.32	1.51	1.28	11.8	13.5	11.4
Hagley, TAS	9-Nov	1.46	1.44	1.23	13.1	12.9	11.1

Note: (MJ/m2/d/^{o}C>0) Mega joules/metre^{2}/day/^{o}C greater than zero)

In recent work conducted by FAR Australia and CSIRO, the GRDC's Hyper Yielding Crops project has allowed us to redefine the upper limit of yield potential associated with different values of PTQ (Figure 2). However, it should be emphasised that in comparison to the previous PTQ relationship with yield potential (Angus & Peake 2009), the new relationship has been primarily based on winter feed wheat germplasm of European origin compared to spring milling wheat germplasm in 2009 which examined irrigated wheat in northern farming systems.

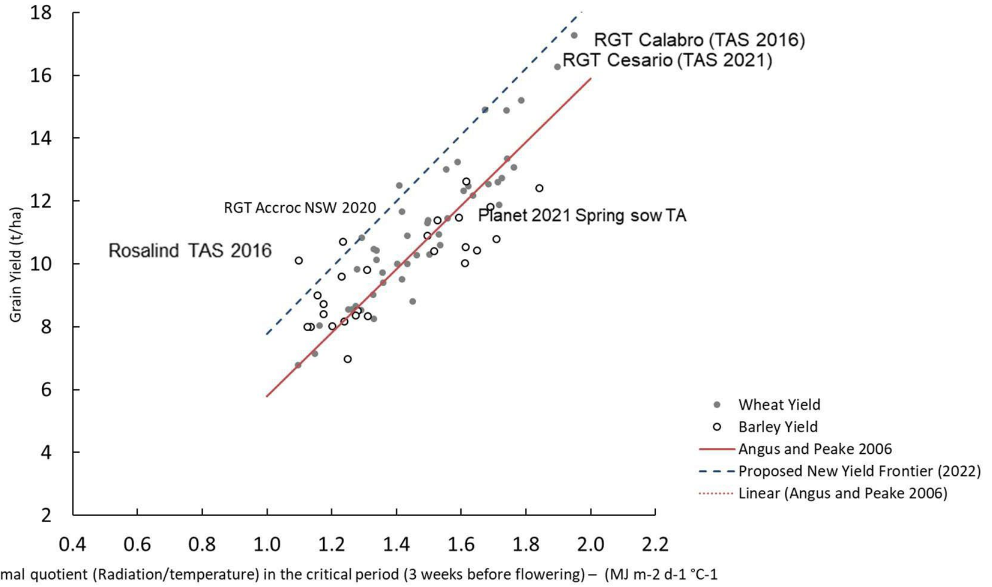


Figure 2. *Relationship between photothermal quotient and grain yield potential in wheat and barley based on recent findings from the Hyper Yielding Crops project (2022)*

Key point summary

- High yields are not a given with irrigation if crops are exposed to poor solar radiation (either by virtue of shorter day length or cloudy weather) or higher temperature.
- The PTQ relationship is a simple method of establishing the yield potential of crops. It is more applicable to crops grown under irrigation than dryland as there is a greater likelihood that soil water and nutrition will not be a constraint to yield.
- The estimations of PTQ revealed that 2020 and 2021 had considerably higher yield potentials than 2022 due to a lack of solar radiation limiting growth in 2022 (as well as water logging).
- It should be remembered that PTQ estimations of yield potential are just that. Realising yield potential is dependent on ensuring that crops are free from constraints of soil water, frost, nutrition, and biotic and abiotic stresses such as disease or pests.

2.2 Longer and later optimum flowering windows for irrigated crops

Another key difference between dryland and irrigated crops has been illuminated by the University of Tasmania (UTAS) team led by Associate Professor Matt Harrison. ***Their modelling research using APSIM (Agricultural Production Systems sIMulator) has shown that irrigated crops have longer optimum flowering periods that are also later than their equivalent dryland crops. So why is this important?*** Optimum flowering date for a particular environment is a balance of risks, with crops flowering too early the grower is faced with frost risk which can reduce yield, flower too late and the crop can be exposed to excessive heat, and, if dryland, soil water stress. With irrigated crops it means that if flowering windows are wider and later growers have greater flexibility in sowing windows and germplasm choice compared to that of dryland growers; whilst irrigation doesn't free us from heat stress, it does free us from soil water stress and terminal drought. Therefore, with later plantings, despite flowering 7-10 days later, timely irrigation means that optimum yields can still be achieved. In addition, since the flowering window is wider, it means a wider range of cultivars with different season lengths can be grown successfully from similar sowing dates without the same concern that optimum flowering window will be missed. With wider and later optimum flowering windows under irrigation (typically 1 – 2 weeks later in the APSIM simulations), it means that longer season cultivar choices can be chosen without the same fear that yields will be reduced due to lack of soil water availability during the grain fill stage. This effect of later and wider optimal flowering windows can also be observed in dryland crops in springs that are wetter, or where mild spring temperature predominate such as 2021. Remembering that the flowering date and the critical period for grain/seed number formation are related means there are greater opportunities for crops to exploit longer daylength (solar radiation) if flowering windows are later under irrigation, particularly if the spring temperatures are milder. The following APSIM simulations carried out by UTAS illustrate just how much wider the modelled optimum flowering period is for irrigated vs dryland crops in the Murray/Murrumbidgee regions where project research has been carried out (Figure 3a & 3b).

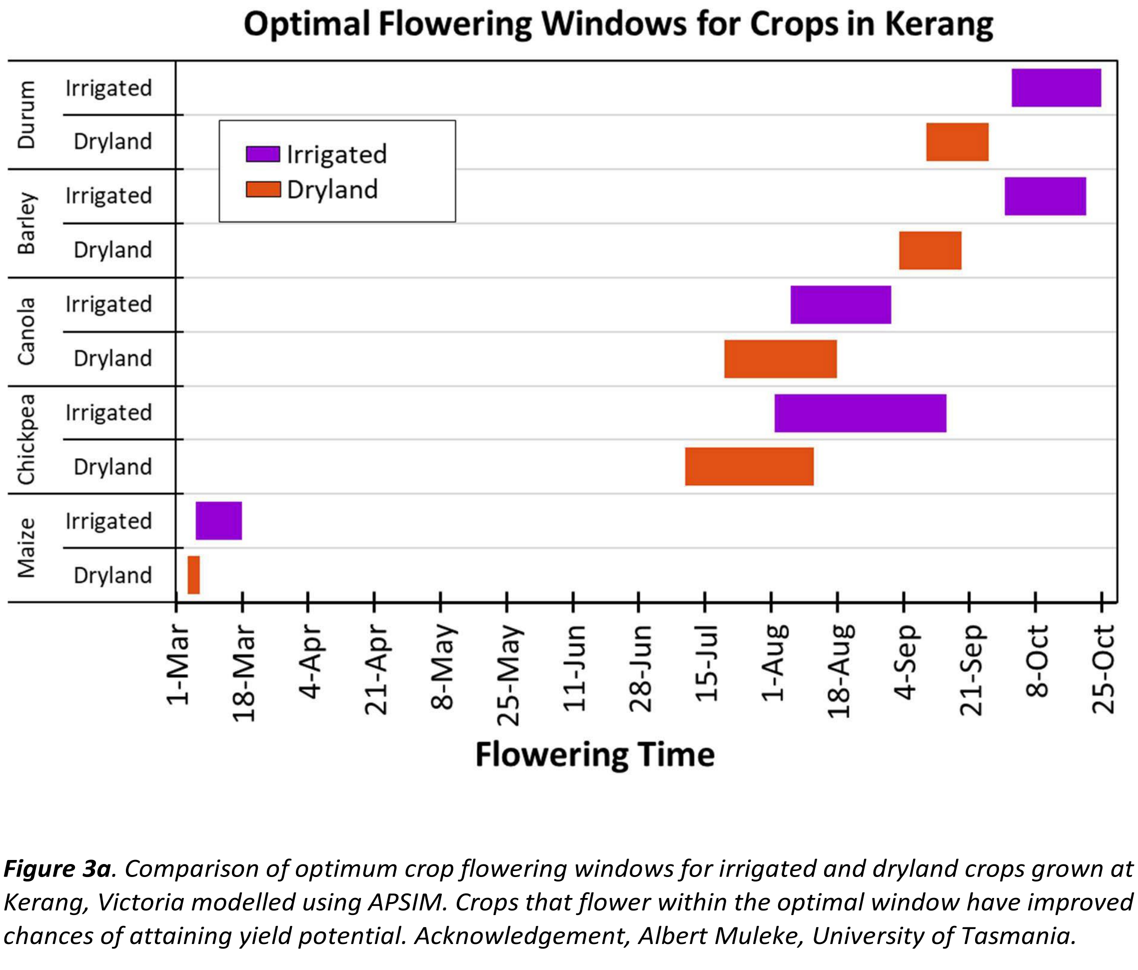


__Figure 3a__. Comparison of optimum crop flowering windows for irrigated and dryland crops grown at Kerang, Victoria modelled using APSIM. Crops that flower within the optimal window have improved chances of attaining yield potential. Acknowledgement, Albert Muleke, University of Tasmania.

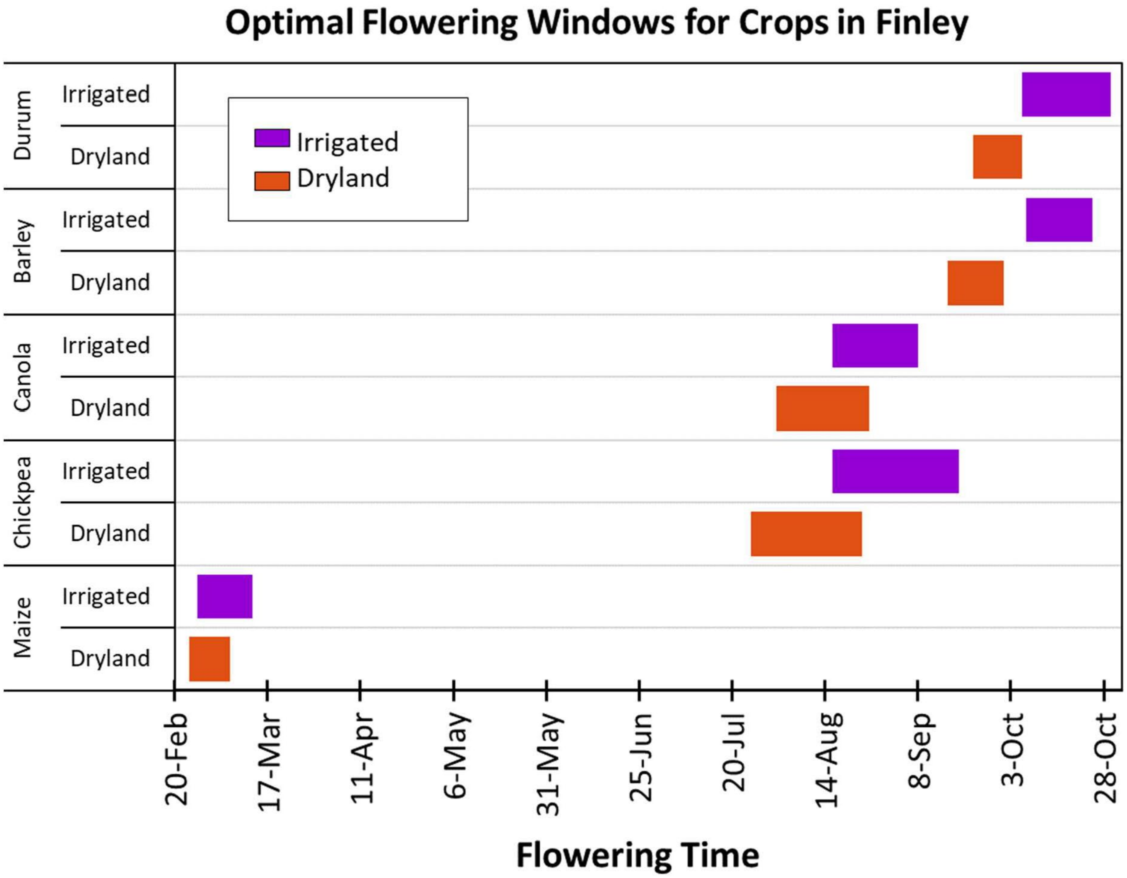


Figure 3b*. Comparison of optimum crop flowering windows for irrigated and dryland crops grown at Finley, NSW modelled using APSIM. Crops that flower within the optimal window have improved chances of attaining yield potential. Acknowledgement, Albert Muleke, University of Tasmania.*

Note: Please note that modelled flowering dates for maize and chickpeas are still under model development and require more validation data to support them.

Key point summary

- On average optimum modelled flowering windows for irrigated crops were 1 – 2 weeks later than their equivalent dryland crops in the regions where the project was delivered.
- Since timely irrigation potentially frees the grower from soil water constraints to yield, it also results in a wider optimal flowering window compared to dryland crops.
- The practical significance of this is that a wider range of varieties with different season lengths can be successfully grown from a similar sowing date under irrigation.
- Conversely, later sowing dates that would be deemed to be too late in a dryland scenario could be employed successfully under irrigation.
- Note however, that with any biological system there is a limit to the extremes tolerated, and as we see from Photothermal Quotient (PTQ,) calculations irrigation does not protect the crop against excessive heat stress.

2.3 General agronomy principles for irrigated crops

Whilst Section 4.0 on crop agronomy will look at the project's specific crops in detail, the following section addresses some of the key pointers in achieving high yields with irrigated farming systems that have been noted in this project. Before covering these general agronomic pointers there is ***one overarching consideration with the agronomy of higher yields and that is you cannot manage what you do not measure. This is particularly important for irrigation soil moisture monitoring (see section 2.5).***

"The Irrigated Eight" for good management. Eight key pointers critical to achieving higher yields from irrigated crops:

1. Pick a cultivar that has four key attributes; high yield potential, good standing power, good all-round disease resistance and the phenology (speed of development) that suits the sowing date, remembering that irrigated crop canopies are invariably larger than their dryland equivalents so are potentially more disease and lodging prone.
2. Match the phenology or "speed of development" of the cultivar to the sowing date to avoid early frost risk and later heat stress. But remember that irrigation gives greater flexibility with cultivar choice and sowing date as optimum flowering windows are later (1-2 weeks) and wider than their dryland cohort, meaning for example, that longer season cultivars can be grown more successfully as a result of soil water constraints being wholly or partially removed.
3. Wider and later optimum flowering windows under irrigation also mean that crops or cultivars suited to later sowing can be grown more successfully, for example irrigated durum which achieved yields of 7-9t/ha in the project from later May sowing.
4. Higher final harvest biomass (dry matter) of irrigated crops gives rise to higher yield potential but it is the crop's high final harvest biomass combined with higher harvest index (proportion of biomass that is grain) that produces high yielding crops. Conversion of biomass to grain is king!
5. If irrigated crops are larger and contain more dry matter at harvest, it's logical their nutrient requirements are higher, however on the plus side the efficiency of nutrient uptakes is also invariably higher.
6. Higher nutrient requirement of larger irrigated crop canopies is frequently supplemented with higher levels of nitrogen mineralisation and more efficient use of soil mineral N reserves when soils are wet and warm. As a result, irrigated crops requiring nitrogenous fertiliser e.g. cereals, grain maize, canola have rarely given yield responses to N fertiliser inputs above 200-250kg N/ha in this project, even when yields have been exceptional. Good farming rotations leading to high levels of inherent fertility are essential to underpin high yields in irrigated farming systems.
7. When available (label recommendations for the crop being grown)plant growth regulators (PGRs) are more important in irrigated crops as canopies are larger and more prone to lodging. This is particularly the case where variety choice has excluded the use of stiffer strawed varieties.
8. Irrigated crop canopies stay greener for longer and are invariably denser than that of dryland crops, which in turn induces higher humidity and more disease than dryland crops, particularly when susceptible varieties are grown. As a result, disease management is more critical with susceptible varieties, therefore consider more robust fungicide strategies either in terms of more persistent fungicides (better actives, higher rates) or more applications. Denser crop canopies under irrigation require higher water rates to achieve canopy penetration with fungicide inputs.

2.4 Pre-irrigation - pros and cons

The 2022 season exposed all the decision-making surrounding pre-irrigation; paddock layouts with poor drainage, spring water logging, winter/early spring drought scenarios resulting in irrigation applications in July where water was available. In many cases in 2022 the only irrigation applications made to paddocks were in the autumn or winter as the spring was so wet.

Three years of the GRDC's Optimising Irrigated Grains (OIG) project, in addition to research conducted under the 'Smarter Irrigation for Profit' project, have highlighted the importance for growers in making good irrigation decisions in terms of how and when to use their irrigation water in order to set up their irrigated crops to be the most profitable.

The changing irrigation environment has seen irrigation water become an input where the price can be highly variable based on seasonal conditions and allocations. Efforts to make irrigation more efficient has seen investment in improved layouts and infrastructure such as overhead sprinklers or fast flow surface irrigation, giving growers flexibility in the amount of water applied and the choice of crops.

Pre-irrigation (where fallow paddocks are irrigated prior to the sowing of a crop) has always been a judgment call by irrigators, based on timing to enable timely sowing, and adequate moisture for the crop to develop over winter. Using surface irrigation could mean using anywhere between 0.75 to 2.0 Megalitres/ha (75-200mm/ha) to wet up the soil profile. The timing of pre-irrigation must be considered in order to allow the paddock to dry sufficiently to enable sowing on time, but not to dry too much and then be at the mercy of 'the autumn break' for sowing similar to a dryland grower.

Many irrigators have a story about the pre-irrigation that went badly – where it rained, and sowing couldn't proceed, or winter waterlogging was detrimental to the crop as the soil profile was full going into winter. However, pre-irrigation does provide soil moisture over winter as some irrigation regions do not have access to water between 15 May and 15 August to allow the water authorities to service and repair the water delivery network.

Irrigators have installed overhead irrigation as a means to be able to have more control over the amount of water applied. Instead of the large volume of water applied via surface irrigation as a pre-irrigation, growers can apply enough water to ensure timely establishment of their crop. This can be a considerable saving of water but does then run the risk of a 'winter drought' if the winter period is dry and winter rainfall is inadequate to meet the needs of the crop. In these cases, yield potential is lost before the irrigation water becomes available in the spring. In shorter season crops, or in warmer regions where spring growth occurs earlier (before mid-August), yield potential starts to reduce since crops are stem elongating, but without the water reserve to sustain this period of rapid development.

The OIG project, with its geographically diverse project partners, has illustrated the different thinking that drives growers' decision making on irrigation. Higher rainfall regions are unlikely to pre-irrigate due to the risk of autumn irrigating leading to waterlogging if they go into winter with a full profile. Similarly, those in the east of the Murray and Murrumbidgee valleys are more confident of a timely break for sowing and follow-up winter rainfall to get the crop through to the spring when irrigation can commence. Those to the west who have soils (e.g. grey clays) that require more water to fill the profile, are less confident of the break being in late April/early May and have lower winter rainfall to tide them over until the irrigation season opens in the spring. Depending on the crop type, restoration of yield potential with spring irrigation following a winter drought can be more limited with early maturing spring wheat, since it has already started developing rapidly whilst the crop is under spring drought conditions. In some cases, the restoration of yield potential is adequate (e.g. faba beans), but this does depend on whether heat stress was additional to the lack of soil moisture and therefore becomes part of the yield equation. These geographical differences also manifest themselves in the responses to disease management where irrigation does not appear to favour conditions that promote the fungal diseases, compared to the naturally more disease prone high rainfall zones.

Drainage and paddock aspect has also been noted as a key part of decision making, with some growers avoiding pre irrigation using surface flow systems on paddocks prone to water logging, or which have poor drainage.

Key point summary

- Water savings can be made with improved irrigation infrastructure such as overhead sprays, particularly on soil types where smaller amounts of irrigation (10-20mm) can be used to bring crops up in the autumn.
- Irrigation districts have varying access to water during the winter season, with some irrigators having no access from mid-May to mid-August.
- Not having sufficient soil moisture going into winter may leave the crop susceptible to 'winter drought', that can have a negative impact on yield.
- Negative effects of a 'winter drought' are likely to be most evident in earlier maturing germplasm that has started to stem elongate prior to water allocations coming back on stream.
- Similarly, having a full soil profile at the beginning of winter may increase the risk of waterlogging, particularly with surface irrigation in systems that don't drain well.
- Soil type, location and appetite for risk all play a part in irrigators' decisions regarding pre-irrigation.

2.5 Scheduling - Measuring water use under irrigation. Its importance to optimum irrigation.

Irrigation decisions: Yield potential in irrigated cropping is built with a combination of variety selection, sowing date, fertility and soil moisture. As irrigators, we have a degree of control over ensuring soil moisture (although not entirely under our control as demonstrated in 2022). Irrigation districts in the southern Murray Darling Basin have different operating rules, different allocation policies and rainfall reliabilities that make an irrigator's decision different for these diverse circumstances.

As a guide, when the crop has used 50% of the plant available water from the soil profile, then it is time to irrigate to avoid stressing the plant.

Irrigation decisions should be based on objective data around available soil moisture; there are three main sources of this data:

1. **Climate.** Using evapotranspiration figures in combination with a crop factor (sourced from Australian data) that calculates the amount of water used by the crop, based on its stage of development, is relatively simple but does result in a requirement for daily calculations to ensure accurate assessment of soil moisture available. There are assumptions to be made about soil type, plant available water in the soil, rooting depth and crop stage so the correct crop factor is used, and these can affect the accuracy of the calculated water usage of the crop.

Comment: This method was used in conjunction with soil moisture monitoring when growing the maize trials in the summer of 2021/22. There are various sources of evapotranspiration data available – some actual readings (and always working in hindsight), and others calculated for a district, that provide *both past and predicted evapotranspiration in order for growers to have the ability to estimate when an irrigation would be required. This resulted in daily calculations to determine the expected water use, as well as corrections of predicted versus actual evapotranspiration, and keeping a running tally to know when irrigation was required. It did seem to match the soil moisture monitoring figures quite well when used with the Kerang maize trials.*

Finding the appropriate ***crop factor*** *for a crop, and then for the growth stage or time of the season is not simple. Many versions are available on the internet, and with varying degrees of environmental specificity. Growers are able to obtain a copy from agricultural departments based on FAO values, covering most of the irrigated crops; a condensed version is presented in Table 1.*

Table 1. *Crop factor (Kc) for irrigated broadacre crops (courtesy of Agriculture Victoria).*

Crop type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Canola				0.35	0.36	0.66	1.07	1.15	1.09	0.61		
Chickpeas					0.40	0.60	0.98	1.00	0.95	0.56		
Faba Bean					0.50	0.54	0.98	1.15	1.15	0.85	0.41	
Lentil					0.40	0.44	0.92	1.10	1.10	0.82	0.41	
Maize Grain	1.13	0.81	0.62						0.30	0.40	0.99	1.20
Sorghum	0.72								0.30	0.45	0.94	0.99
Soybeans	0.88	1.15	1.15	0.98	0.60							0.40
Sunflower	1.15	0.76								0.35	0.45	1.02
Wheat/Barley					0.30	0.50	1	1.15	1.11	0.58		

To calculate the crop water use for the day, multiply the daily evapotranspiration by the crop factor, subtract any rainfall, and then keep a running tally to see when the water use matches the amount of plant water your soil has available for the crop. E.g. a day in September may have a daily evapotranspiration of 4.3mm, therefore the crop water use would be 4.3 x 1.09 or 4.7mm for canola or 4.3 x 1.11 or 5.0mm for wheat. Adding these figures to the previous daily totals since the profile was full/irrigation will assist in keeping a track of the water used by the crop and when the next irrigation should occur.

2. **Soil Moisture Monitoring.** SMM has been widely adopted by many growers. The two main types are gypsum blocks (Watermark sensors) and conductance probes. Gypsum blocks are relatively simple to install and measure the applied tension or pressure required to extract the soil water, and the measurements displayed are applicable to all soil types. Conductance probes can measure soil water at various points in the soil profile, these do however need calibrating for specific soil types. Both types can be set up for remote monitoring and do need to be set up in a representative area.

Comment: ICC have been using both types of SMM options for many years. Gypsum blocks are relatively easy to install but decisions must be made about what depth the blocks need to be installed at (there is usually a limit to the number of blocks that can be read by the logger), and there has been variation in readings from different blocks at the same depth. The key advantage of gypsum blocks is that they read water tension and so the refill point value is the same no matter what the soil type is. Capacitance probes give a better 'view' of what is happening down the soil profile, but the refill point is a different value depending on the soil type. ICC have had probes installed and the software has a refill point nominated but this has often been a best guess, with the gypsum block system being used to calibrate the set up. If you do want to install a capacitance probe, make sure you get after sales service to ensure it is set up for your soil.

3. **Remote Sensing.** Irrisat is a satellite system which assesses the moisture status of a crop, it then predicts when irrigation should occur based on soil type and an accurate plant available water value.

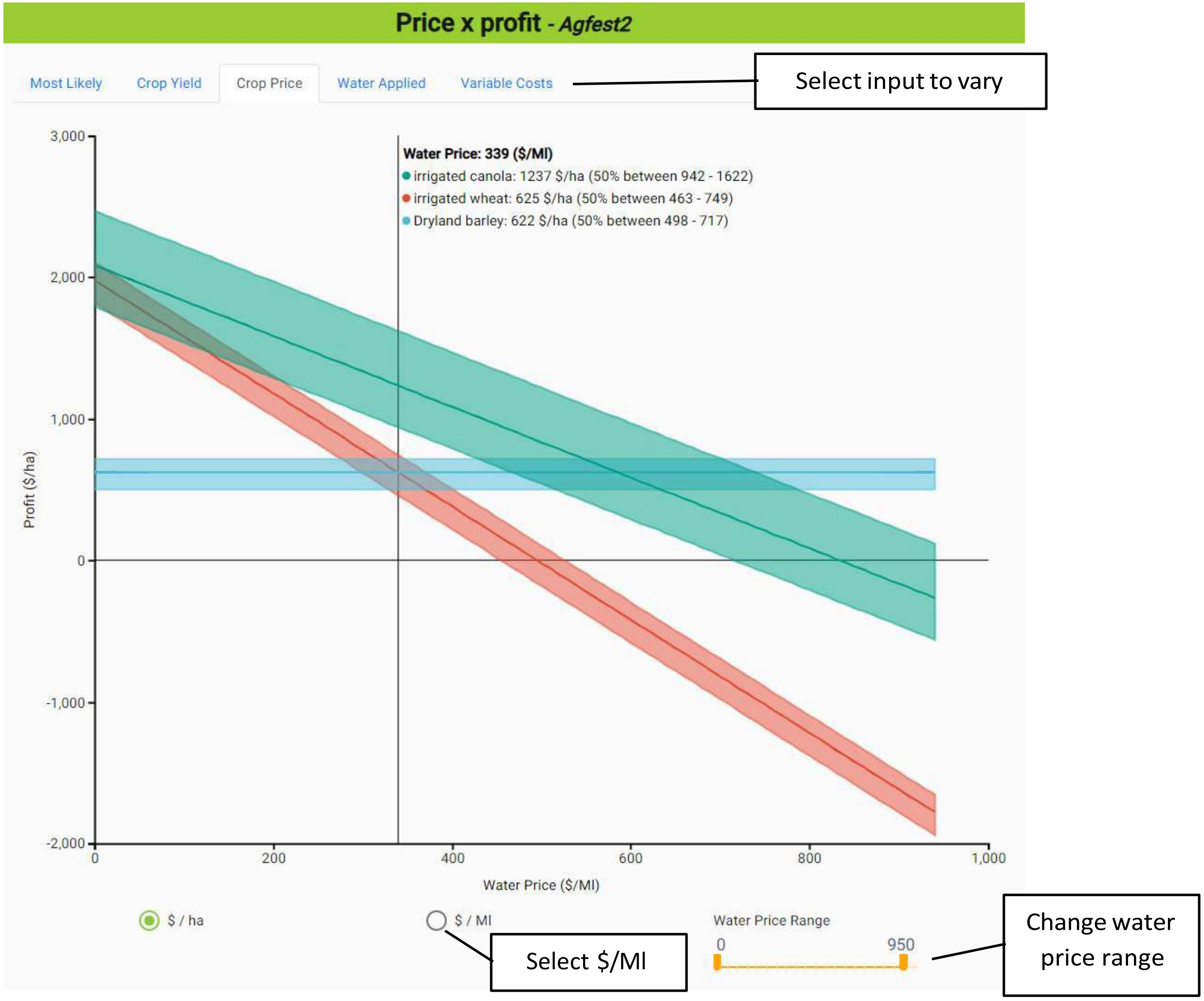
No comment as this method has not been used by project team members.

2.6 WaterCan profit

As part of the project, the University of Tasmania (UTAS) team developed an online calculator and phone app, **WaterCan Profit**, which is freely available online for farmers and their advisers. It enables whole-farm sensitivity analysis that considers water price, irrigation layout and scheduling, variable input costs and grain price to optimise farm scale returns from allocating available water to alternative crops. It includes three applications:

1) **Water Price**, which shows the gross margins of the user's crops by water price, given in $/hectare or $/Mega Litre (Ml) of water. This allows users to test the relative profitability of their cropping options for different water prices, showing the cross-over point between crops, the breakeven point for each crop, and to compare the relative merits of irrigated and rainfed crops.

Water Price Example



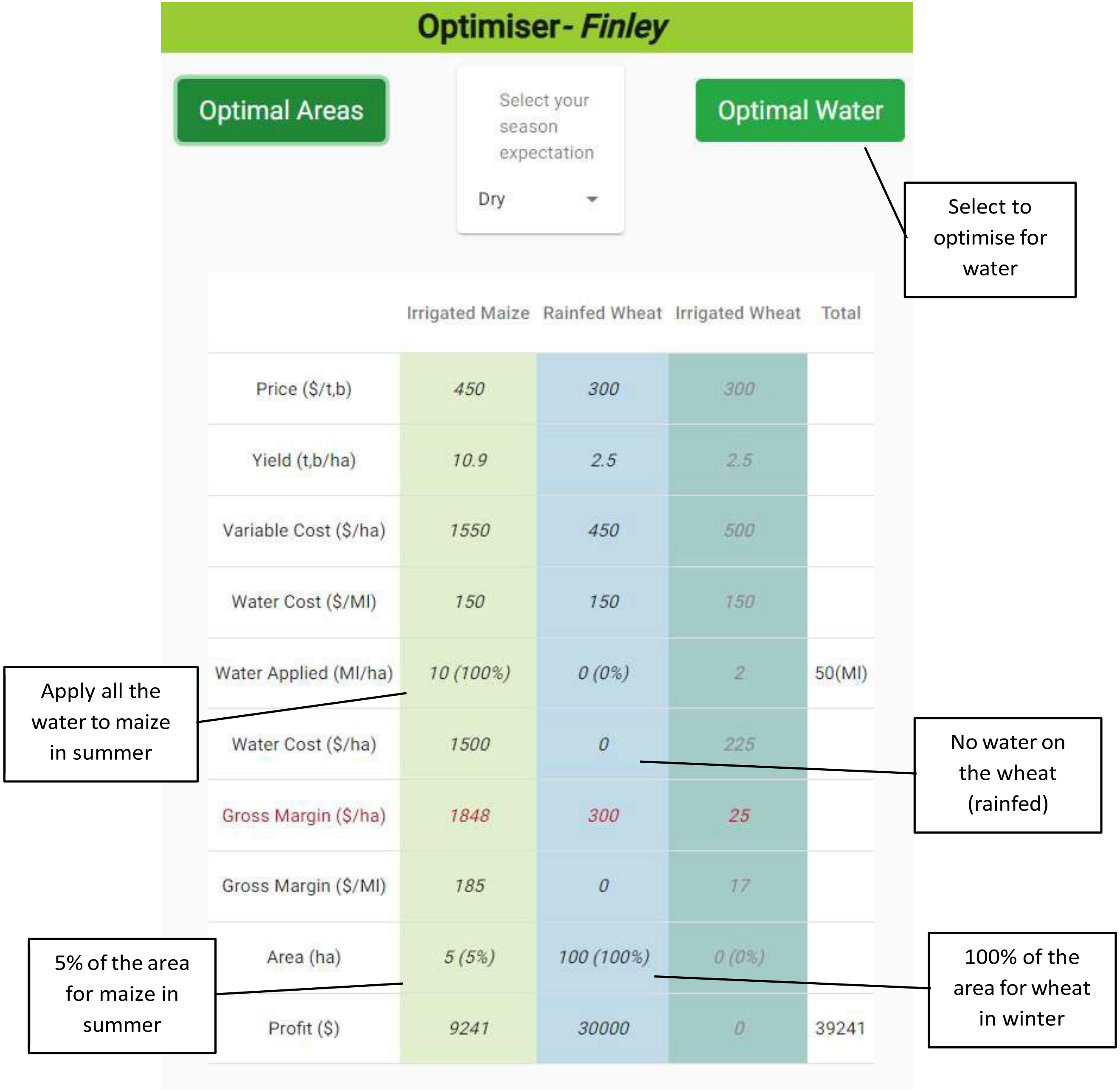
Price x profit - Agfest2

Water Price: 339 ($/Ml)
- irrigated canola: 1237 $/ha (50% between 942 - 1622)
- irrigated wheat: 625 $/ha (50% between 463 - 749)
- Dryland barley: 622 $/ha (50% between 498 - 717)

__Figure 1.__ An example of an output graph from the Water Price app. Profit is given against water price for input crops showing crossover points between crops, breakeven points and ranges due to variation in crop price. Variation in yield, amount of water applied, and costs can also be displayed. Results can be displayed in $/ha or $/Ml. Range of water prices to display can also be selected.

2) **Optimiser,** which optimises water use across crop rotations, showing how much water to use on each crop in your rotation to maximise profits given water price, and when it may be more profitable to sell water back into the water market.

Optimiser example – Finley, NSW



Optimiser- *Finley*

Select your season expectation: Dry

	Irrigated Maize	Rainfed Wheat	Irrigated Wheat	Total
Price ($/t,b)	450	300	300	
Yield (t,b/ha)	10.9	2.5	2.5	
Variable Cost ($/ha)	1550	450	500	
Water Cost ($/Ml)	150	150	150	
Water Applied (Ml/ha)	10 (100%)	0 (0%)	2	50(Ml)
Water Cost ($/ha)	1500	0	225	
Gross Margin ($/ha)	1848	300	25	
Gross Margin ($/Ml)	185	0	17	
Area (ha)	5 (5%)	100 (100%)	0 (0%)	
Profit ($)	9241	30000	0	39241

Select to optimise for water

Apply all the water to maize in summer

No water on the wheat (rainfed)

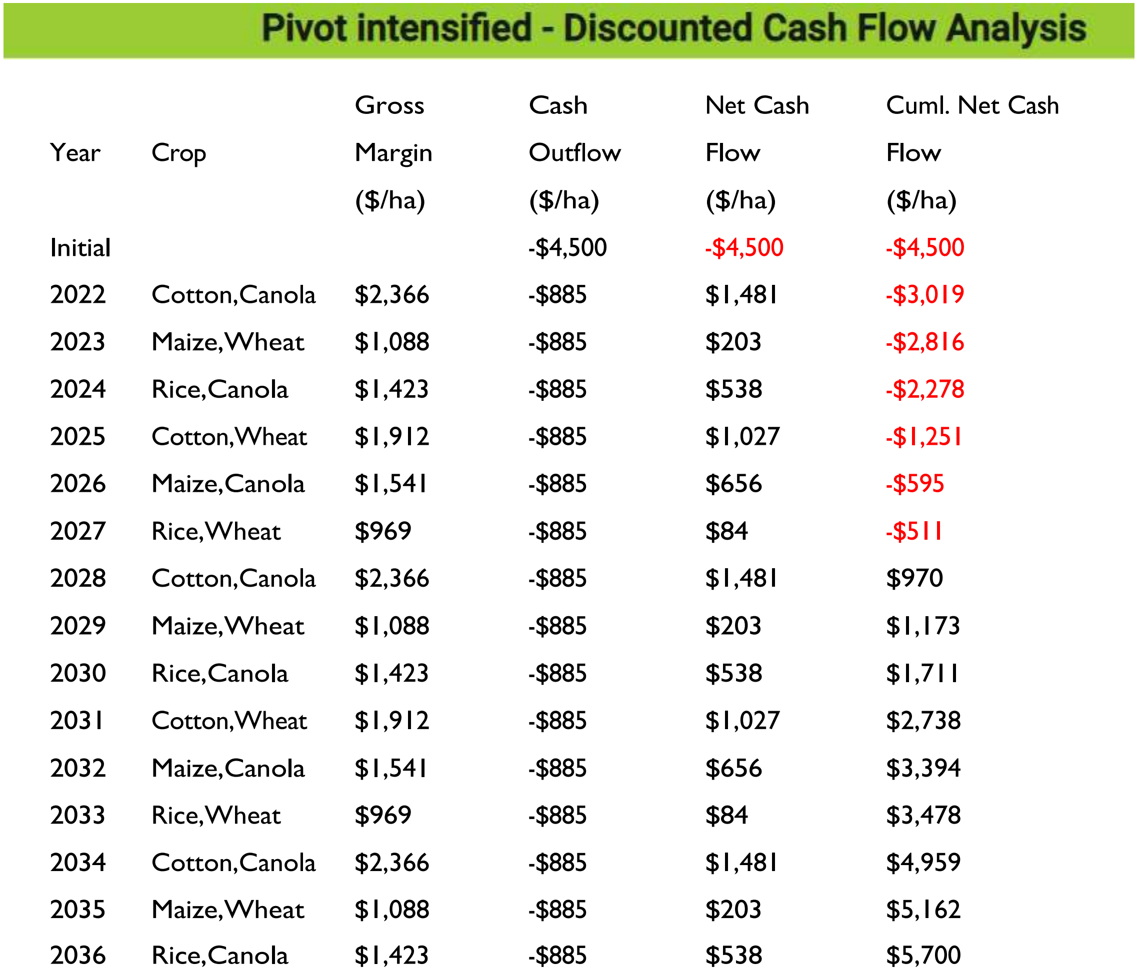
5% of the area for maize in summer

100% of the area for wheat in winter

Figure 2. *Example output from the Optimiser application. With a rotation of summer irrigated maize and winter wheat it finds it optimal to use all of the water on the summer maize and to grow rainfed wheat in winter. Five percent of the area would be irrigated and all of the area used in winter. It is also possible to optimise for water.*

3) **Investment,** which shows the cash flows from investment in alternative irrigation systems, giving their net present value, internal rate of return and payback periods.

Investment example



Pivot intensified - Discounted Cash Flow Analysis

Year	Crop	Gross Margin ($/ha)	Cash Outflow ($/ha)	Net Cash Flow ($/ha)	Cuml. Net Cash Flow ($/ha)
Initial			-$4,500	-$4,500	-$4,500
2022	Cotton,Canola	$2,366	-$885	$1,481	-$3,019
2023	Maize,Wheat	$1,088	-$885	$203	-$2,816
2024	Rice,Canola	$1,423	-$885	$538	-$2,278
2025	Cotton,Wheat	$1,912	-$885	$1,027	-$1,251
2026	Maize,Canola	$1,541	-$885	$656	-$595
2027	Rice,Wheat	$969	-$885	$84	-$511
2028	Cotton,Canola	$2,366	-$885	$1,481	$970
2029	Maize,Wheat	$1,088	-$885	$203	$1,173
2030	Rice,Canola	$1,423	-$885	$538	$1,711
2031	Cotton,Wheat	$1,912	-$885	$1,027	$2,738
2032	Maize,Canola	$1,541	-$885	$656	$3,394
2033	Rice,Wheat	$969	-$885	$84	$3,478
2034	Cotton,Canola	$2,366	-$885	$1,481	$4,959
2035	Maize,Wheat	$1,088	-$885	$203	$5,162
2036	Rice,Canola	$1,423	-$885	$538	$5,700

Net Present Value: $2,725 ($/ha)
Internal rate of return: 14 (%)
Payback period:7 (y)

Figure 3. *Sample output from the Investment application showing gross margins for each year after an investment in pivot irrigation and cumulative net cash flow from the intensified cropping system. NPV/ha for the investment is given with the internal rate of return and the payback period.*

These calculators were developed through extensive consultation with the irrigation user and adviser community, both before and during development. This included farmers, agronomists/advisers, consultants, irrigation salespeople, OIG project facilitators, other agricultural application/model developers and agronomic researchers.

The WaterCan Profit application is now available for both Android and iOS. Users can download and install the app on their mobile devices from the Google Play Store and iOS App store.

3. Crop Agronomy – key guidelines from project results

The following section of the booklet looks at the results from the project achieved over the three years. As was presented in the introduction, these results should be read remembering that the 2020-2022 period was characterised by a three-year period when La Nina weather patterns prevailed.

3.1 Highest and lowest irrigated yields achieved in the research project 2020 – 2022

In the four tables below (Table 1), the project team present the highest yields and their associated gross margins as a way of looking at the most profitable crops grown over the period of the project. So that all crops are comparable, the prices for the commodities have been based on 2023 grain values.

Table 1. *Highest and lowest yields (and associated gross margins) achieved in the project's crops from 2020 – 2022 research using 2023 commodity prices. (Based on results from the Murray and Murumbudgee research sites at Kerang and Finley).*

Highest Project Yields – Finley, NSW (machine harvested). Grain maize, Peechelba, Victoria.

Crop	Highest Yield (t/ha)	Year achieved	Input costs	Gross Margin $/ha*	Irrigation applied (Mega litres Ml)	Irrigation at $200/Ml (value $/ha)
i) Summer Crop						
Grain Maize	19.36	2019-20	2099	5645	6.1	1220
ii) Winter Crop						
Canola	5.20	2021	930	2710	0.83	106
Durum	8.77	2020	1059	2449	2.1	420
Faba beans	7.88	2021	695	2220	0.9	180
Chickpeas	3.66	2020	555	1641	2.1	180
Barley	10.10	2021	939	2394	2.24	448

Highest Project Yields – Kerang, Victoria

Crop	Highest Yield (t/ha)	Year achieved	Input costs	Gross Margin $/ha	Irrigation applied (Ml)	Irrigation at $200/Ml (value $/ha)
i) Summer Crop						
Grain Maize	19.40**	2019-20	1348	6411	9.8	1960
ii) Winter Crop						
Canola	4.49	2021	930	2213	3.9	780
Durum	10.55	2020	1059	3161	4.3	860
Faba beans	7.88	2020	695	2220	4.2	840
Chickpeas	4.88	2020	555	2373	2.1	420
Barley	8.27	2021	939	1790	3.9	780

** Gross margin does not include cost of the water as this is seasonally dependent*

***This yield was not machine harvested but was a hand harvested crop.*

Lowest Project Yields – Finley NSW.

Crop	Lowest Yield (t/ha)	Year achieved	Input costs	Gross Margin $/ha	Irrigation applied (Ml)	Irrigation at $200/Ml (value $/ha)
Canola	0.83	2021	825	-244	2.89	578
Durum	2.67	2022	586	482	0	0
Faba beans	1.04	2022	527	-143	0.15	30
Chickpeas	0	2022	597	-597	0	0
Barley	5.45	2022	505	1294	0	0

Lowest Project Yields – Kerang, Victoria

Crop	Lowest Yield (t/ha)	Year achieved	Input costs	Gross Margin $/ha	Irrigation applied (Ml)	Irrigation at $200/Ml (value $/ha)
i) Summer Crop						
Grain Maize	9.56	2019	1349	2523	9.8	1960
ii) Winter Crop						
Canola	2.78	2021	825	1221	3.9	780
Durum	2.78	2022	586	526	0	0
Faba beans	3.29	2022	527	690	0	0
Chickpeas	1.52	2022	597	315	0	0
Barley	6.06	2020	505	1495	4.3	860

The results of the project revealed that grain maize was the highest yielding and most profitable irrigated crop, but clearly used the highest amount of irrigation water. This presents an ideal opportunity to employ the WaterCan Profit app in order to consider water price sensitivity using the higher yields achieved. Durum has been the top performer of the winter crops, and although the yields aren't always as high as milling wheat, the price advantage has led to higher gross margins (grower comment since wheat not experimented upon). Canola has generally been a reliable crop, however establishment is always a challenge. The highest and lowest yielding research plots were achieved in the same season, both at Finley 100m away from each other. The canola sown under overhead irrigation achieved good establishment and went on to yield over 5t/ha, however canola planted less than 100m away in a surface irrigation bay was autumn irrigated and follow up rain proved too much (on a poor draining bay) for the young crop to handle resulting in low establishment and yields below 1t/ha. Where seed rates were increased to compensate, yields approaching 2.7t/ha were achieved in the same trial. Barley has been reliable although the gross margins don't match canola and durum. Pulse crops achieved some exciting results, however both faba beans and chickpeas suffered immensely in the wetter year of 2022. Chickpeas in particular proved very sensitive to less than perfect drainage in any year and need well managed disease control strategies to yield well.

3.2 Aspirational yield targets for irrigated crops

But how do these project yields compare to modelling predictions of what is possible at these sites on soils representative of this region? The UTAS modelling team who have led the economics component of the OIG project have used the APSIM model to look at the yield potential by using weather data from the last 111 years. It was asked of them to provide some references that relate to yield potentials in a season that growers will remember and relate to. In the following graphs the highest potential yields have been used for the 2020 season, the first of the project research years (and a year with good yield potential based on PTQ – see Section 2.1). These potential crop yields provide a good reference to the highest yield targets growers can aspire to achieve using representative soils, the physiological constraints of the germplasm and an assumption that management strategy was not limited by soil water, nutrition, disease or pests using modelling based on the reference weather patterns.

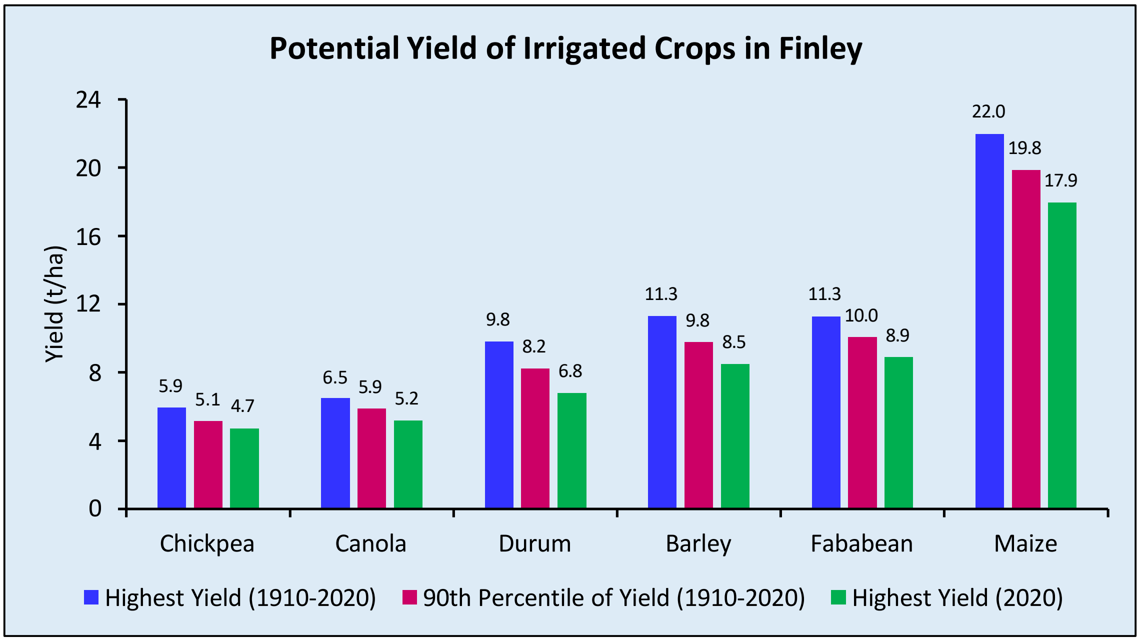


Figure 1a: *APSIM simulations of potential yield for irrigated crops in Finley, NSW. The blue bars represent the highest long-term crop yield from 1910 to 2020. Red bars represent the 90th percentile of long-term yield. Green bars represent highest average annual yield for the year 2020 (Graphics courtesy of Albert Muleke, University of Tasmania).*

The graphs also indicate the highest yields and 90th percentile of yield based on 111 years of weather data (1910-2020).

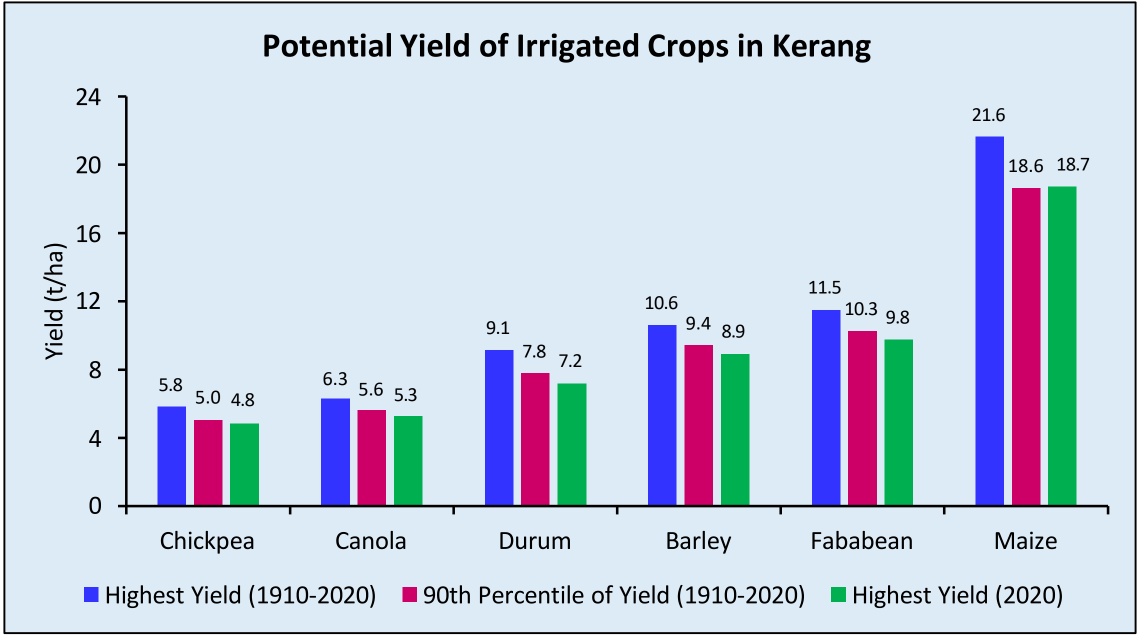


Figure 1b: *APSIM simulations of potential yield for irrigated crops in Kerang, Victoria. The blue bars represent the highest long-term crop yield from 1910 to 2020. Red bars represent the 90th percentile of long-term yield. Green bars represent highest average annual yield for the year 2020. (Graphics courtesy of Albert Muleke, University of Tasmania).*

The most noticeable differences between these modelled potential yields and the results achieved relate to Durum wheat, where project results have shown yields in excess of the modelled yields, since in 2020 Durum crop, yields were in the range of 8.5 - 10.5t/ha with optimum management and germplasm compared 6.8 – 7.2t/ha for modelled potential yields. For other crops, the APSIM yields are higher or similar to the maximum yields realised in the project as result of good management and newer germplasm.

4.0 Good management guidelines

Good management guidelines for the six project crops are set out in the following crop sections which can also be accessed as individual crop specific sections for extension purposes. The guidelines are laid out as key points with a small amount of supporting data taken from the trials conducted over these three years.

Please note these guidelines only cover agronomy topics that were researched during the project (2020 – 2022), it is not intended to be a complete guide to growing irrigated crops. Instead, it carries key points noted to be instrumental in growing productive and profitable irrigated crops.

4.1 GRAIN MAIZE

Nitrogen rates and timing targeting 20t/ha for irrigated grain maize

Key point summary

Nitrogen fertilisers

- Grain maize crops yielding 16 – 19t/ha with dry matters of 33 – 35t/ha commonly remove 400kg N/ha from the soil, but in results generated over the duration of this project (2020- 2022), these crops did not respond significantly to N fertiliser inputs greater than approximately 250kg N/ha.
- Of the nitrogen removed by the crop canopy at harvest, approximately 30 – 35% of the N is returned to the soil as stover residues, so based on a 400kg N offtake approximately 120 - 140kg N/ha was returned to the soil as harvest residues.
- Applications of nitrogen in excess of 250kg N/ha with up to 550kg N/ha experimented upon in the project were largely uneconomic; these applications lost up to $400/ha (in the season of application) depending on the price of N fertiliser and the exact rates of N applied.
- If the additional N fertiliser is "N banked" in the soil, then it may be concluded that a proportion of the excess N fertiliser is recovered the following year, but in terms of economics for the grain maize it was not economic to exceed 250kg N/ha applied.
- Fertility of the farming systems as a whole was shown to provide the additional N nutrition required to produce high yielding crops of 33 – 35t/ha biomass and 16 – 19t/ha grain yields.
- Whilst in an irrigated system it is unclear how much of the excess N is available the following season, research conducted indicates that we need to re-think the profitability of such large N doses in excess of 250kg N/ha, or at a minimum take account of soil mineralisation for nitrogen applications in irrigated summer crops, which logically will be higher in wet and warm soils.
- Whilst we cannot "mine" our soils without regard to this contribution, the research has illustrated that in-crop mineralisation in the summer months is an extremely significant contributor to the N budget calculations under irrigation.
- Additionally, if the farming system is returning grain maize residues to the soil these typically contain 120 - 140kg N/ha with high yielding crops.
- The fertility of the farming system will clearly influence how much mineralisable N can be sourced by the crop, however the work conducted in OIG would suggest that growers need to be circumspect with regards to N applications in excess of 300kg N/ha.
- N timing has failed to generate significant yield effects but there has been some evidence to suggest split applications, with an emphasis on later applications (up to tasselling), has been associated with higher grain protein.
- In addition, if large applications were made at sowing as single doses, there was evidence to suggest nitrification inhibitors (eNpower) have a role, but yield increases were not statistically significant.

Clearly, the level of organic carbon in the soil will vary and contribute different amounts of soil N supply through the course of a season, however the key finding from the OIG project has been our inability to generate significant yield responses up to the levels of fertiliser being applied on farm (250 – 500kg N/ha. The following example graphs indicate at Peechelba (Red loam over clay) and Kerang (Grey clay) in Victoria the grain yield response to applied nitrogen and the partition of N between stover residue and grain at harvest.

A) Peechelba East, Victoria – Overhead Irrigation (6.08 Mega L/ha applied)

Table 1: *Grain yield (t/ha @ 14% moisture) test weight (kg/hL) and harvest index (HI %), 31 May 2020. – Peechelba East, Victoria cv Pioneer hybrid 1756.*

Treatment				**Seed Yield and Quality**		
	Pre-drill kg N/ha	**Post drill* kg N/ha**	**Total kg N/ha**	**Yield t/ha**	**Test Wt kg/hL**	**H.I %**
1	0	207	**207**	18.12 -	81.0 -	49.8 -
2	45	207	**252**	18.80 -	81.0 -	50.3 -
3	90	207	**297**	18.32 -	81.3 -	46.7 -
4	135	207	**342**	19.02 -	81.2 -	45.8 -
5	180 (Farm)	207	**387**	18.63 -	81.3 -	44.9 -
6	225	207	**432**	18.12 -	81.6 -	46.2 -
7	270	207	**477**	18.54 -	80.8 -	47.1 -
8	315	207	**522**	18.34 -	81.2 -	52.3 -
	LSD			NS	NS	NS
	Mean			18.49	81.1	47.8
	P Val			0.991	0.926	0.296
	CV			8.82	1.01	8.99

** Post sowing nitrogen (207 N) was applied via fertigation with applications on V4 (46N), V8 (60N), pre-tasselling (101 N) on 10 Dec, 26 Dec, 14 Jan and Jan 15. Available soil N assessed prior to sowing 33 kg N/ha (0-60cm) Harvest index based on grain and stover recorded at 0% moisture. Previous crop: Oaten hay*

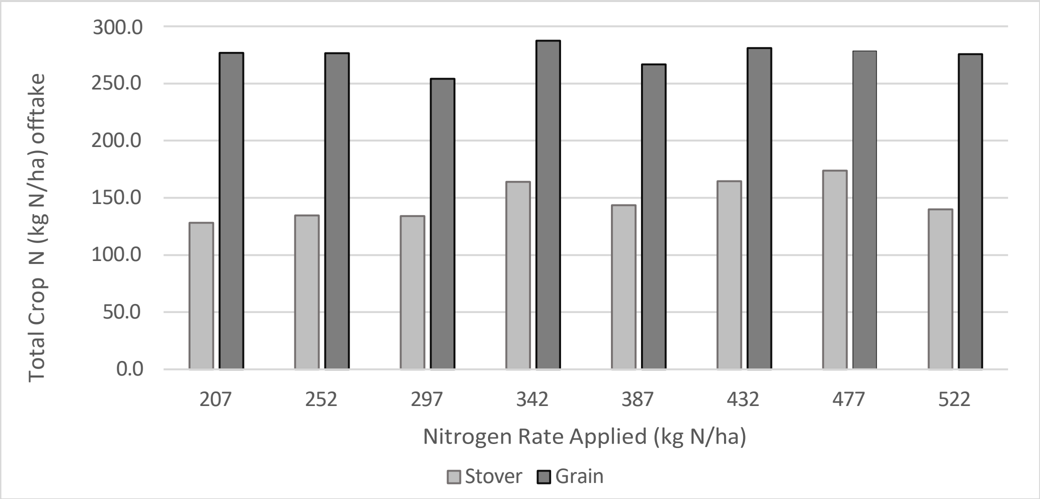


Figure 1. *Total crop N (kg N/ha) offtake at harvest in the stover (stalks, leaves, husk) and grain 31 May 2020. Peechelba East, Victoria cv Pioneer hybrid 1756.*

B) Kerang, Victoria – Flood Irrigation (9.6 Mega L/ha applied)

Table 2: *Grain yield (t/ha @ 14% moisture), dry matter (t/ha), test weight (kg/hl) and harvest index, 20 May 2022 cv Pioneer hybrid 1756.*

Treatment				**Grain Yield, Dry Matter Yield and Quality**					
				Yield		**DM**		**Test Wt**	**H.I**
	Pre-drill	**Post drill**	**Total kg**	**t/ha**		**t/ha**		**kg/hL**	
1	0	0	**Nil**	10.34	d	22.64	d	81.7	0.40
a	40	40	**80**	11.98	c	29.33	c	82.7	0.36
3	80	80	**160**	15.05	bc	33.94	bc	83.0	0.39
4	120	120	**240**	17.13	a	31.42	ab	82.0	0.47
5	160	160	**320**	16.66	ab	32.53	ab	80.0	0.44
6	200	200	**400**	17.76	a	35.56	ab	80.7	0.43
7	200	200	**480**	17.04	a	33.66	a	81.1	0.44
8	280	280	**560**	17.03	a	34.28	a	80.9	0.43
	LSD Yield	**(p=0.05)**	1.659	**P Val**		<0.001		cv%	7.3
	LSD DM	**(p=0.05)**	3.398	**P Val**		<0.001		cv%	5.8
	LSD Test Wt	**(p=0.05)**	ns	**P Val**		0.094		cv%	1.8
	LSD HI	**(p=0.05)**	ns	**P Val**		0.059		cv%	11.0

Figures followed by different letters are considered to be statistically different (p=0.05) Available Soil N prior to sowing and watering up was 34 kg N/ha (0-60cm). The nil control N offtake at harvest was 241 kg N/ha, suggesting in-crop mineralisation resulted in 207 kg N/ha of the N taken up. Previous crop: Grass dominant pasture (3 years).

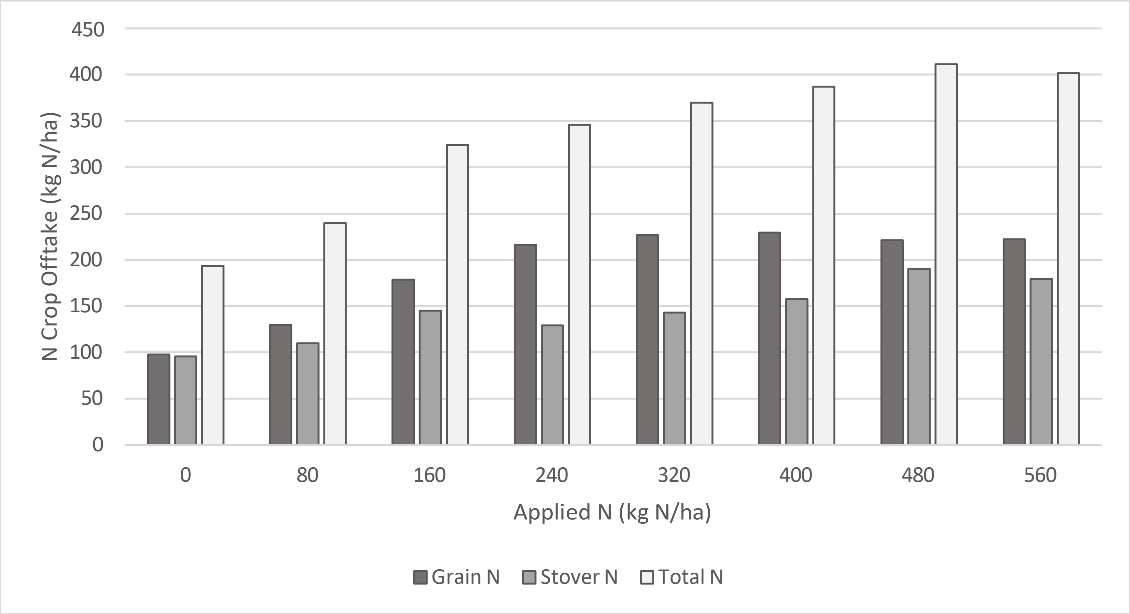


Figure 2. *Total crop N (kg N/ha) offtake at harvest in the stover (stalks, leaves, husk) and grain 31 May 2022. Kerang, Victoria cv Pioneer hybrid 1756.*

Key point summary

Foliar feeding and additional basal fertilizer

- The project, with the assistance and support of industry, evaluated a number of different foliar applications of both macro and micronutrients in 2021 and 2022 applied in addition to grower standard practice.
- These liquid fertilisers (based on calcium nitrate and Natures K), whilst influencing biomass were not observed to increase grain yield.

Crop structure and Plant population

- Results suggested no disadvantage to narrower 500mm row spacing compared to 750mm in OIG project work.
- Advantages of narrower row spacing was more pronounced when plant population was increased, since narrower rows gave better plant spacing within the row compared to wider rows.
- However, the differences in biomass and grain yield between narrow row and wider row spacing were rarely statistically significant.
- For the highest yielding scenarios (18 – 19t/ha) experienced in the project, the optimum population for a cost-effective return with Pioneer hybrid 1756 was approximately 90- 93,000 plants/ha.
- Lower yielding maize on maize rotation positions gave optimum populations no higher than this when using the 1756 hybrid.
- Later sowing of grain maize (Pioneer hybrid 9911) in the third week of December did not respond to increasing plant population between 78,000 and 102,000 plants/m2.

Fungicide application in grain maize

- In the five fungicide trials conducted on grain maize there was no benefit from using either DMI triazole fungicides (prothioconazole) or QoI strobilurin (pyraclostrobin) fungicides in OIG grain maize trials.
- There were no significant yield effects of fungicide application at either V8 (8 leaf) or V14 in the absence of noticeable disease.
- Despite strobilurin fungicides being associated with greater green leaf retention in cereals, no such effects were observed in these trials.

4.2 BARLEY

Germplasm, Crop structure and Plant population

Key point summary

- Irrigated barley benefited from PGR application with greater yield benefits associated with crops that are irrigated earlier in the grain fill period.
- The spring barley RGT Planet (8.13t/ha) was significantly higher yielding than Cassiopee winter barley (7.83t/ha) when averaged over two years (2020 & 2021) and over four treatments in a plant growth regulator trial at the Finley Irrigated Research Centre (IRC).
- Applying a plant growth regulator (PGR), either as a split application (GS31 & GS33) or as a single application (GS31) resulted in a significantly higher yield compared to the untreated crops, averaged over both varieties over two years.
- Weaker strawed cultivars such as Cassiopee were less suited to irrigated farming systems, particularly when soil fertility was higher, however these crops were also in general more responsive to PGR.
- The winter barley Cassiopee experienced significantly more lodging than RGT Planet and was less suitable for irrigated systems. PGR application did reduce lodging, although in Planet differences in lodging were relatively small.
- PGR application and grazing both had a similar reduction (average 7cm) in crop height compared to the untreated plots when measured over both varieties and both years.
- Defoliation of RGT Planet at GS30-31 to simulate grazing generated 722kg DM/ha RGT and 1937 kg DM/ha in Cassiopee, illustrating the longer vegetative growth phase in winter germplasm.
- Valued at 25 cents per kg/dry matter the dry matter was valued at $180/ha and $484/ha respectively for Planet and Cassiopee, which in both cases compensated for the loss of grain yield with defoliation.
- Grazing a late April sown Planet required a minimum 4 cents/kg return on dry matter (DM) to offset the grain loss associated with 722kg DM/ha removal at GS30, whilst with Cassiopee it was 8 cents/kg DM when 1937kg DM/ha was removed at GS30. To grow Cassiopee in place of Planet in order to take advantage of the extra forage required 19 cents/kg DM to counter the loss of $359/ha in grain.
- Over the three years of evaluation (2020 – 2022), there was lower soil N available at sowing (lower fertility) in the later years that has resulted in the weaker strawed crop being easier to manage in terms of lodging control.
- Given lower fertility scenarios under irrigation, optimum nitrogen timings have been centred on two applications split in the period from GS30 – 33. Earlier than this promotes much greater lodging risk, later than this increases protein but not necessarily yield an important consideration in terms of malting barley production.

Irrigated barley at the Finley IRC has consistently shown yield benefits to the application of Plant Growth Regulators (PGRs) in the OIG project, even though responses have not always been statistically significant (Figure 1).

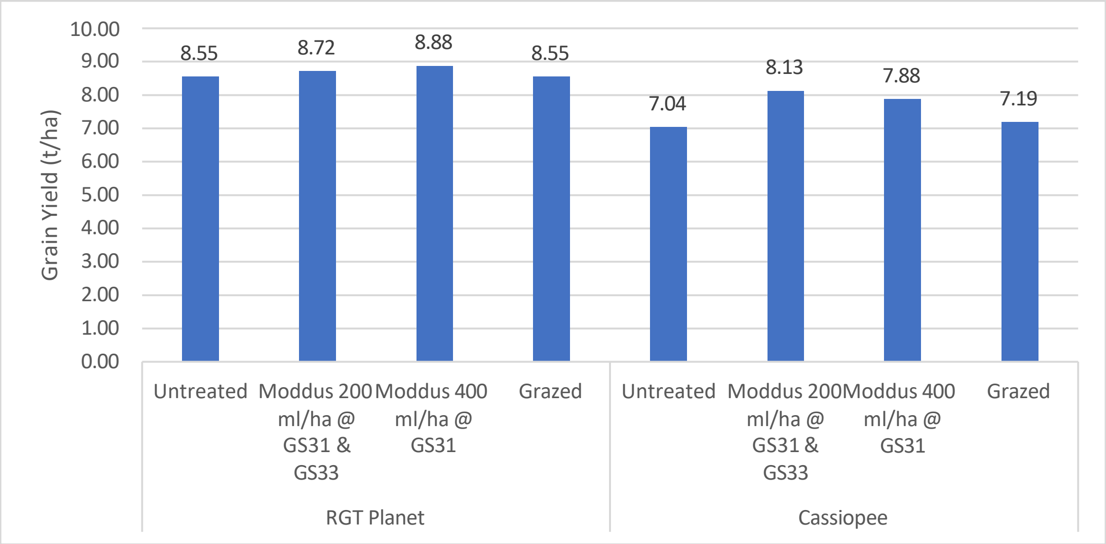


Figure 1. *Influence of plant growth regulator on seed yield (t/ha) using RGT Planet spring barley and Cassiopee winter barley in 2 irrigated trials conducted at Finley – 2020 and 2021.*

These PGRs, either single applications or splits of Moddus Evo (trinexapac ethyl) have been observed to reduce or delay the onset of crop lodging during grain fill. It is this reduction and delay in lodging that is related to the yield increases that have been observed (Figure 2).

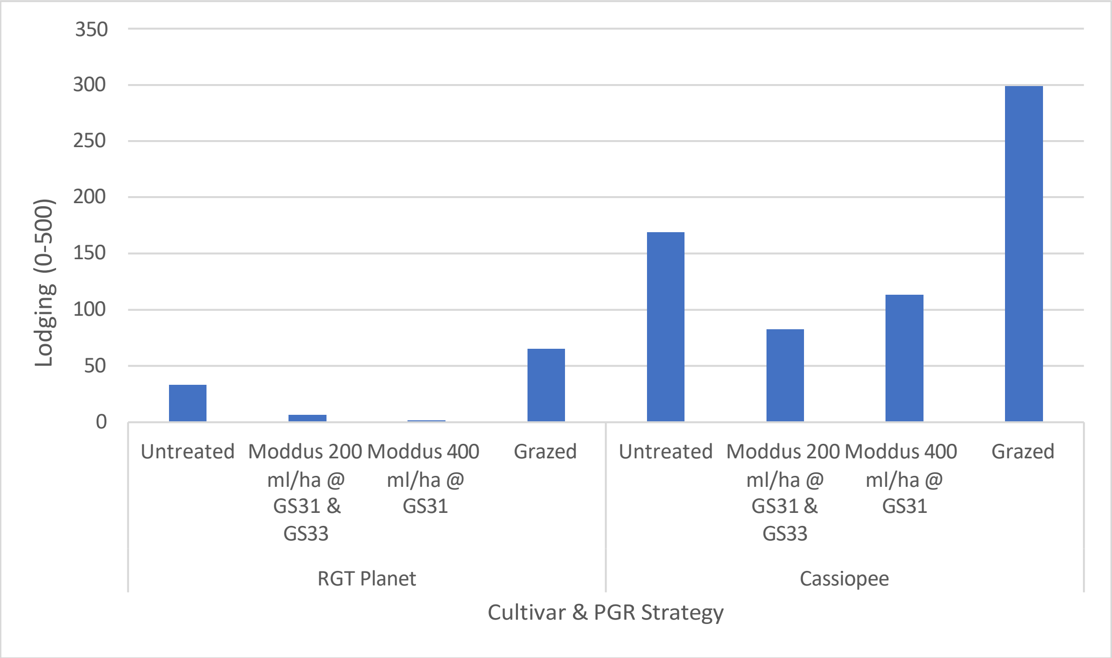


Figure 2. *Influence of plant growth regulator on crop lodging using RGT Planet spring barley and Cassiopee winter barley in 2 irrigated trials conducted at Finley – 2020 and 2021.*

Defoliation of the crop at GS30-31 (start of stem elongation) to mimic the effect of grazing produced significantly more dry matter with the winter barley that reached stem elongation later in the spring cultivar than Planet (Figure 3).

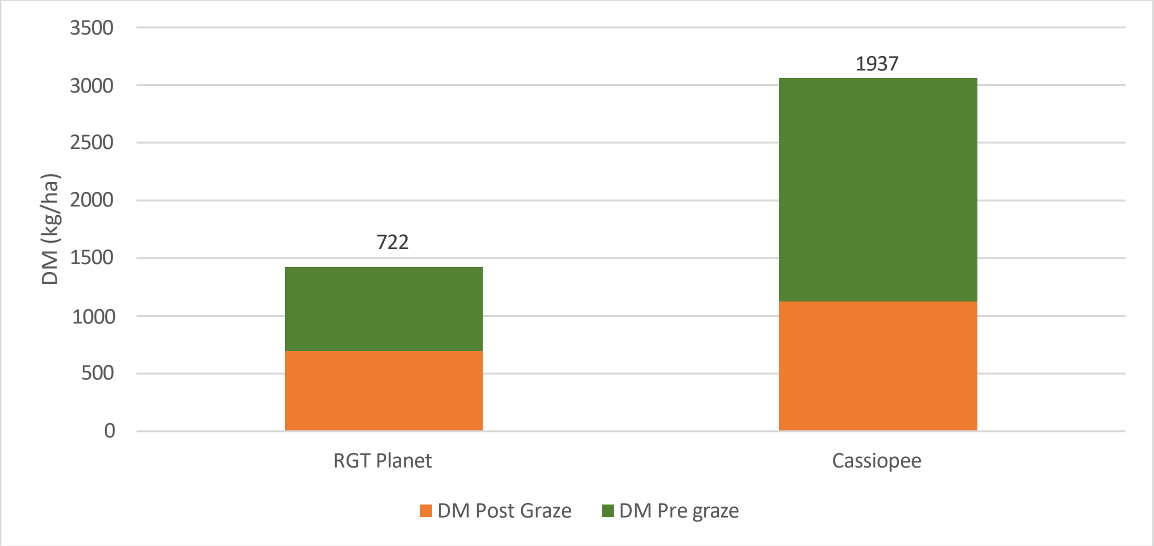


Figure 3. *Influence of cultivar on dry matter (DM) kg/ha harvested by simulated grazing using a lawn mower to remove biomass at GS30-31 in two years of trials at Finley – 2020 and 2021. Figures above bars show the amount of biomass removed by "simulated" grazing.*

The return in $/ha from PGR application with Planet was marginal, since the split application of Moddus (GS31 and GS33) was less cost effective than the untreated, whilst the single application (GS31) was slightly more cost effective. With the weaker strawed winter barley Cassiopee both single and split applications were very cost-effective applications (Table 1).

Table 1. *Net income ($/ha) after PGR treatment, exclusive of grazing income and other input costs.*

Cultivar	Treatment	Yield (t/ha)	Gross Income[1] ($/ha)	PGR cost[2] ($/ha)	Net Income[3] after PGR ($/ha)
RGT Planet	Untreated	8.55	2052	-	$ 2,052
	Moddus Split GS31 & GS33	8.72	2092	61.72	$ 2,030
	Moddus @ GS31	8.88	2130	46.72	$ 2,083
	Grazed	8.55	2052	-	$ 2,052
Cassiopee	Untreated	7.04	1688	-	$ 1,688
	Moddus Split GS31 & GS33	8.13	1950	61.72	$ 1,888
	Moddus @ GS31	7.88	1890	46.72	$ 1,843
	Grazed	7.19	1724	-	$ 1,724

[1]Gross income based on $240/t for feed barley delivered Finley, (protein was above 12% for all treatments in these trials and therefore unable to achieve malt quality). [2]PGR cost based on Moddus Evo at $79.30/L and application cost of $15/ha. [3]Net income has no other costs of production included only the PGR costs and its application cost.

Table 1 does not include the value of dry matter grazed at GS30-31. In Table 2 the value of the reduction in grain yield equates to a value for DM to justify grazing. In RGT Planet only 4 cents/kg DM was required to offset grain loss associated with removal of 722kg DM at GS30. With Cassiopee where defoliation produced nearly 2t/ha DM the grain loss at harvest was greater (0.94t/ha compared to

PGR treated) and 8 cents/kg DM was required to offset grain loss compared to the most effective PGR treatment or to warrant growing Cassiopee instead of RGT Planet 19 cents/kg DM.

Table 2. *Grazing value ($/ha) required to ensure same income as ungrazed, PGR treated plots grain yields.*

			Penalty for grazing cf. highest net income ($/ha)		**c/kg required from GS30 DM to offset grain loss**	
Cultivar (Grazed)	Net Income ($/ha)	Grazed DM (kg/ha)	cf. Planet ($2083/ha)[1]	cf. Cassiopee ($1888/ha)[2]	$2083/ha	$1888/ha
RGT Planet	$ 2,052	722	-31		$ 0.04	
Cassiopee	$ 1,724	1937	- 359	-164	$ 0.19	$ 0.08

[1] Gross income achieved with RGT Planet and single PGR application. [2] Gross income achieved with Cassiopee and split PGR application.
cf. Compared to

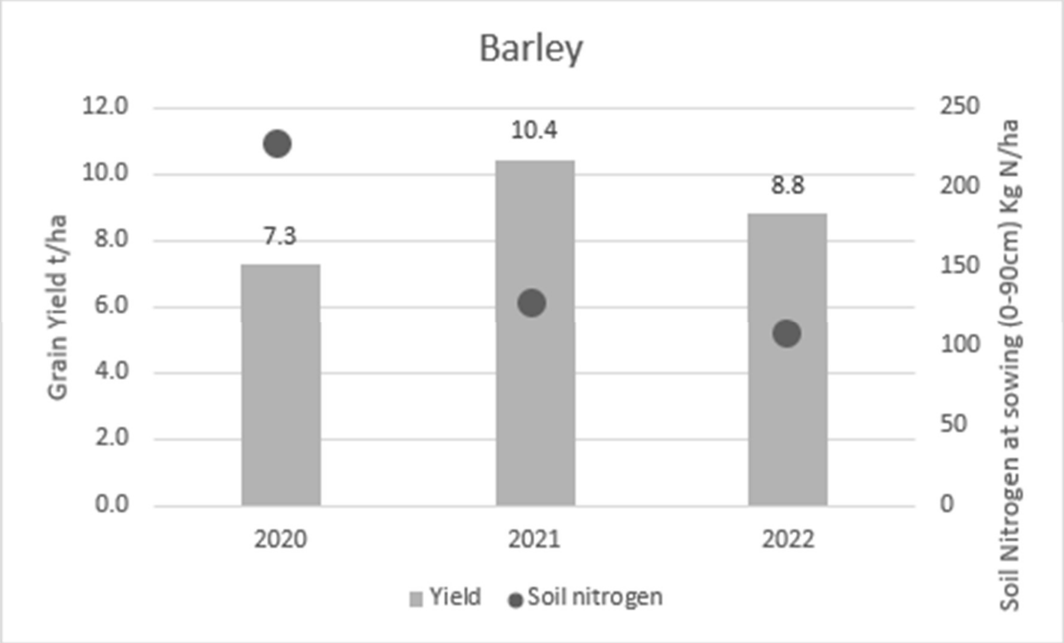


Figure 4. *Highest yields of barley in the OIG project and the relationship to soil nitrogen available in the soil in the autumn of growing those crops – Finley, NSW.*

4.3 CANOLA

Crop structure and Plant population

Key point summary

- The penalty for growing canola crops that are too thin is significant under irrigation.
- At $700/t the influence of thinner canola populations can result in productivity losses of $448
- $532/ha.
- Under irrigation it's better to have hybrid canola populations that are too thick than too thin when assessing seedbed conditions and establishment.
- 80 seeds/m2 resulting in plant populations averaging 43-45 plants/m2 were the most profitable populations tested under surface and overhead irrigations systems.
- If autumn surface irrigation 80-100mm (0.8-1.0 Mega litre) was followed by heavy winter rainfall on poorly drained red duplex soil, canola establishment could be severely reduced (2-9 plants/m2) and productivity reduced to yields of 1-2.5t/ha.
- Under irrigation at Finley the yield advantage of RR hybrid over TT hybrid was 17% (0.64t/ha) resulting in a $488/ha increase in productivity at $700/t.
- In the warmer irrigation region of Kerang on grey clay the advantage of the RR hybrid was approximately half that observed at Finley with a yield advantage valued at $231/ha.
- Higher plant populations resulted in test weights that achieved the minimum standard (62kg/hL) which was not the case with the lowest TT plant populations tested.

Growing canola under irrigation with the aim of producing 5t/ha has illustrated significant penalties in yields and margins from growing crops that are too thin. With higher yield potential under irrigation small differences in plant population have a "magnifying" effect in terms of yield. With plant populations below the optimum there are significant yield penalties, whilst in the same varieties' populations that might be regarded as above the optimum have been either equal or higher yielding than the optimum. As a result, dropping to populations between 10-20 plants/m^2 can produce a significant drop in productivity compared to plant populations that are above 40 plants/m^2 when canola has been grown under irrigation. In the research looking at optimum crop canopy performance for irrigated canola the following key points emerged in 2020 and 2021.

Influence of hybrid RR vs. TT

- Higher yields under irrigation magnify differences relative to dryland. Roundup Ready hybrid 45Y28 has been consistently higher yielding than the hybrid TT HyTTec. A mean 17% advantage (range 15-18% mean 0.64t/ha) was observed at Finley Irrigated Research Centre worth $448/ha at $700/t.
- The advantage of 45Y28 over HyTTec Trophy in the warmer region of Kerang on grey clay was approximately half that observed at Finley (9%-0.33t/ha) worth $231/ha.

Influence of plant population

- Roundup ready hybrid 45Y28 has shown 15% higher productivity (mean of 0.64t/ha) from an average plant population of 45 plants/m^2 (based on 80 seeds/m^2) compared to populations of 14 plants/m^2 (based on 20 seeds/m^2) (Figure 1). Thicker canopies based on 45 plants/m^2 under irrigation generated a $448/ha return for an investment of approximately $110/ha in extra hybrid seed planted (additional 3kg/ha seed). Approximately $4 return for each $ spent on additional seed.
- The differences in hybrid TT populations under irrigation produced even greater differences in productivity and again illustrated that growing crops with higher plant populations was important to secure the additional productivity offered by irrigation. Hybrid TT HyTTec Trophy showed 23% higher productivity (mean of 0.76t/ha) from a mean population of 43 plants/m^2

with this thicker crop generating an additional $532/ha return from a similar $110/ha investment in additional seed. Approximately $5 return for each $ spent.

Influence of irrigation system (relative to winter rainfall)

- The poorest yield results observed in the project resulted from autumn irrigation immediately post sowing in early May following sowing in late April. Poor drainage and flow of surface irrigation at the Finley site led to early winter water logging and very low plant establishment. Crop establishment that fell to between 2-9 plants/m^2 yielded 0.83-2.67t/ha with 45Y28 and 3-7 plants/m^2 with HyTTec Trophy yielding 1.14-1.71t/ha.

The results illustrate that under irrigation the penalty of growing crops too thinly is increased with very large losses of income if population falls to 10-15 plants/m^2. Although hybrid plant populations of 25-30 plants/m^2 removes much of this penalty, productivity and profitability was increased further with populations at 40-50 plants/m^2, despite the additional cost of seed.

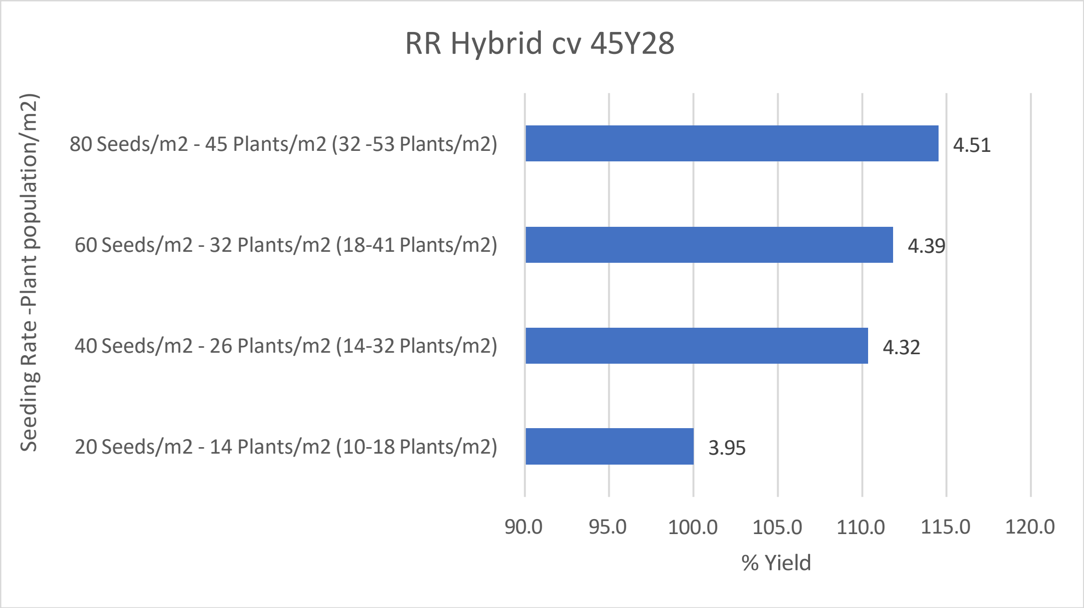


Figure 1. *Influence of plant population on seed yield (t/ha) using the RR hybrid 45Y28 in 6 irrigated trials conducted at Finley and Kerang – 2020 and 2021.*

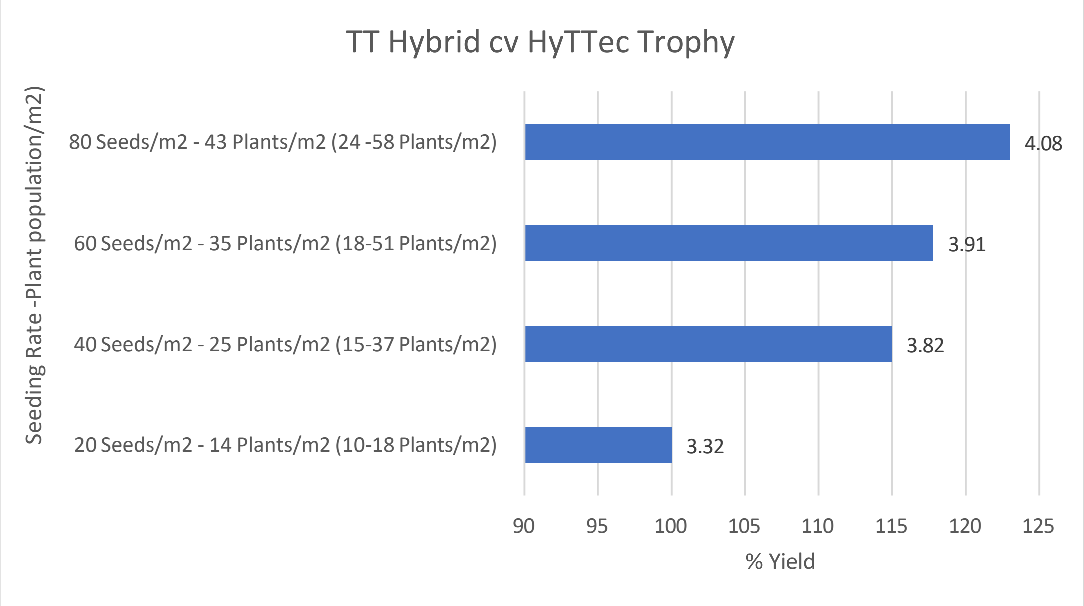


Figure 2. *Influence of plant population on seed yield (t/ha) using the TT hybrid HyTTec Trophy in 6 irrigated trials conducted at Finley and Kerang – 2020 and 2021.*

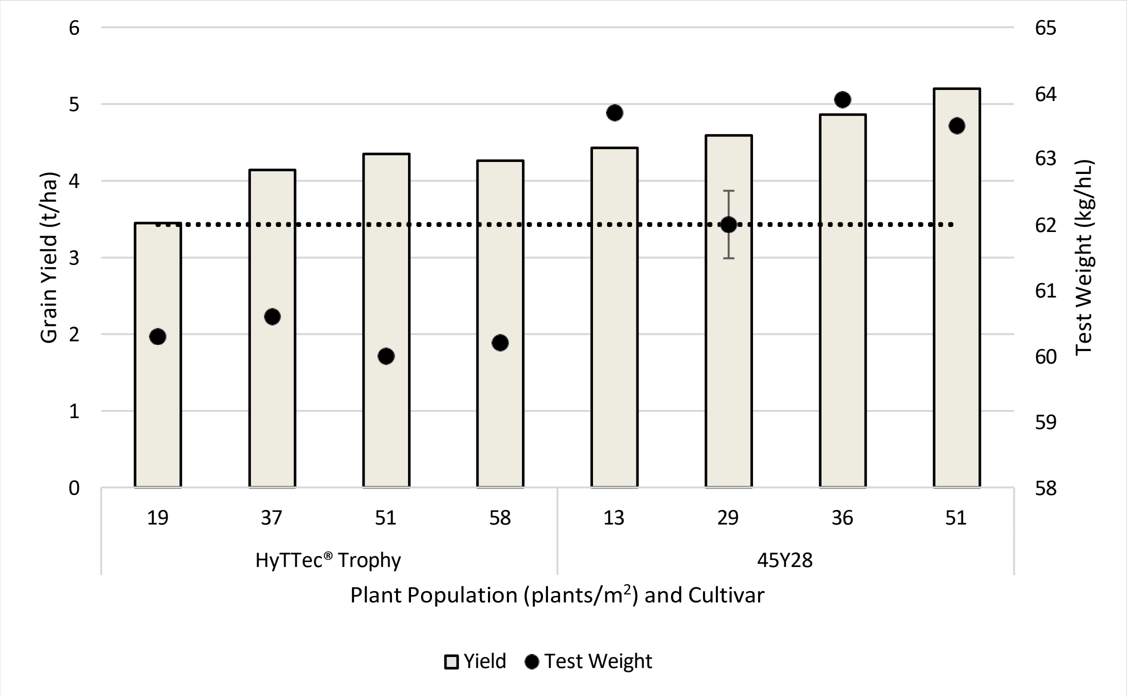


Figure 3. *Influence of plant population and cultivar on seed yield (t/ha) and test weight (kg/hL) using the TT hybrid HyTTec Trophy - Finley 2021.*

Nitrogen applications for 5t/ha irrigated canola

Key point summary

- Growing 5t/ha canola crops under irrigation does not require very large quantities of artificial nitrogen, it requires a fertile farming system that enables large crop canopies to draw down from a high soil N reserve in order to satisfy crop demand.
- Optimum N rates in OIG project trials required to grow 4-5t/ha canola crops did not exceed 240kg N/ha applied as N fertiliser (urea 46% N).
- At Finley 200kg N/ha would be an appropriate target with a range of 160-240kg N/ha (upper end of range with low soil fertility or lower rate of range with high fertility).
- In trials conducted, there were few, if any differences in seed yield due to N timing with N rate being the most important. Timings of 6 leaf, green bud and yellow bud using split applications made little difference to yield or oil content.
- When crops respond to higher levels of N input (above 240kg N/ha) it is often where crops cannot efficiently access the N fertiliser applied, a common occurrence in dryland scenarios. With irrigated crops the efficiency of N applied is improved considerably.
- The highest yielding irrigated canola crops in the project were produced in paddocks where inherent fertility was high with applied artificial N rates typically no more than 160-240kg N/ha at Finley and 80-120kg N/ha at Kerang.
- These fertile irrigated paddocks can often produce reasonable crops with little or no artificial N as soil N mineralisation provides a greater proportion of the N supply e.g. Finley and Kerang 2020 yields were in excess of 3t/ha achieved with only MAP at sowing.

During 2020 at Kerang on grey clay, canola yields varied from 3.00 – 3.63 t/ha based on 0 to 320kg N/ha applied with an optimum of 80kg N/ha. In 2021 from the same N range the canola yields were 2.74 – 4.36t/ha with an optimum of 120kg N/ha. In Finley during 2020, yields ranged from 3.91 – 4.71t/ha (Figure 4) with an optimum of 160-200kg N/ha and in 2021 from 2.21 – 4.22 t/ha with an optimum of 240kg N/ha from the same yield range.

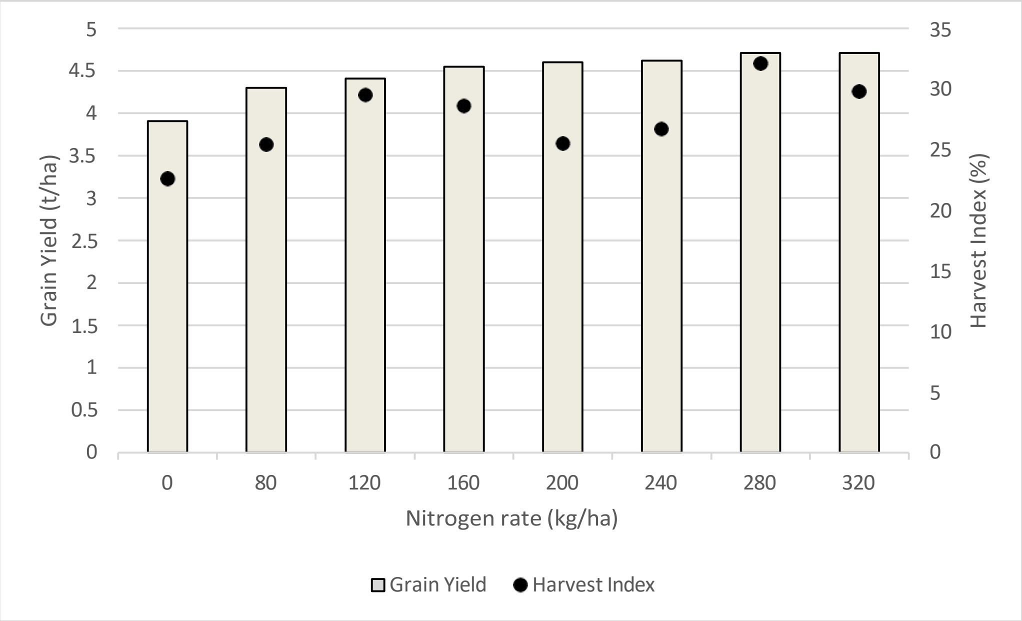


Figure 4. *Influence of applied N rate on seed yield (t/ha) and harvest index (%) – cv RR Hybrid 45Y28, Finley, NSW 2020.*

Disease management in irrigated canola

Key point summary

- In the project trials at Finley in 2020 and 2021, the maximum responses to disease management strategies were relatively small (0.13t/ha and 0.28t/ha) in irrigated canola crops of ATR Bonito.
- The research work conducted on canola was subject to upper canopy blackleg and crown canker but not sclerotinia.
- In these cases, flutriafol in furrow followed by Miravis at 4-6 leaf were the most effective treatments, although the yield increases were small in 2020 and 2021 (only statistically significant in 2021).
- In 2022 the same treatment was amongst the most effective tested, but other yield increases were higher (cv Bonito for all three years).

PGR management – controlling crop height and lodging

Experimental PGR applications (based on a gibberellin inhibitors) have been successfully employed to reduce crop height in irrigated canola, however the effects of the PGR which have been manifest at flowering have largely worn off by harvest. So far, these transient reductions in crop height have not been associated with any improvement in seed yield.

4.4 CHICKPEAS

Crop structure and Plant population

Key point summary

- Chickpea yields under irrigation reached yields over 4.0 t/ha.
- 35 seeds/m2 resulting in plant populations averaging 21-25 plants/m2 were the most profitable populations tested under surface and overhead irrigations systems from a late April sowing.
- The influence of lower chickpea populations can result in productivity losses of 1.0 t/ha.
- Higher yields have come from April sowing compared to May sowing. Where sowing is delayed, populations need to be increased to 35 plants/m2.
- Yields have not been stable over the three years of trials. Yields in 2021 from the Finley site were approximately half that of 2020, with the overhead irrigation suffering the higher yield reduction. Kerang 2021 yields were similar between seasons.
- Drainage is key to success. No podding was observed at Kerang where the soil was held close to field capacity due to frequent rainfall during the period mid-September to late October 2022.
- Lodging was observed in higher plant populations but was also influenced by cultivar choice.

Growing chickpeas under irrigation has demonstrated that there are yield penalties for crops that have reduced biomass and those subject to transient water logging. With early pod set determined by temperature (>15 degree C) and grain fill impacted by high temperatures later in spring, there is a window of opportunity for maximising yield by taking advantage of higher biomass promoted by higher seeding rates or earlier sowing (Figure 1).

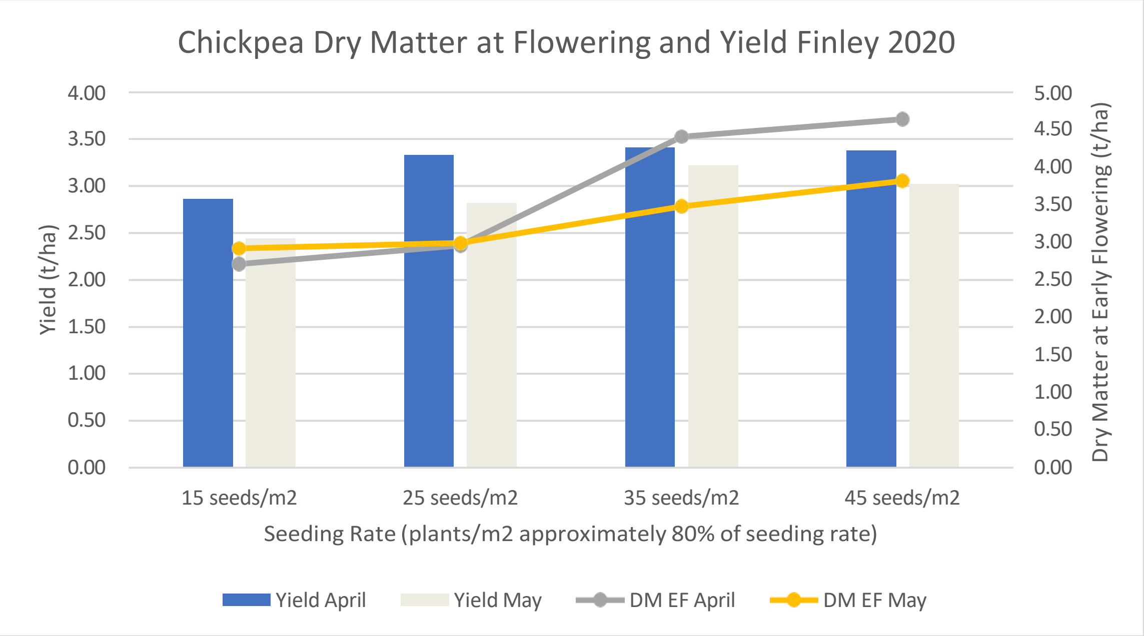


Figure 1*: Chickpea yield and dry matter (DM) at early flower (EF) averaged from two cultivars.*

Inoculation of Chickpeas

Key point summary

- As chickpeas require a specific inoculum (Group N), it is highly recommended that seed be inoculated before sowing.
- Using higher rates of Alosca granules resulted in increased nodulation in 2020 but no difference in 2021 or 2022. Untreated plants had few nodules, but the number was increasing over the 3-year period.
- While yields were lower in the untreated plots, they were not statistically significant.
- High soil N at sowing (109 – 117 kg N/ha 0-60cm) may be reducing the reliance on fixed N in the crop.

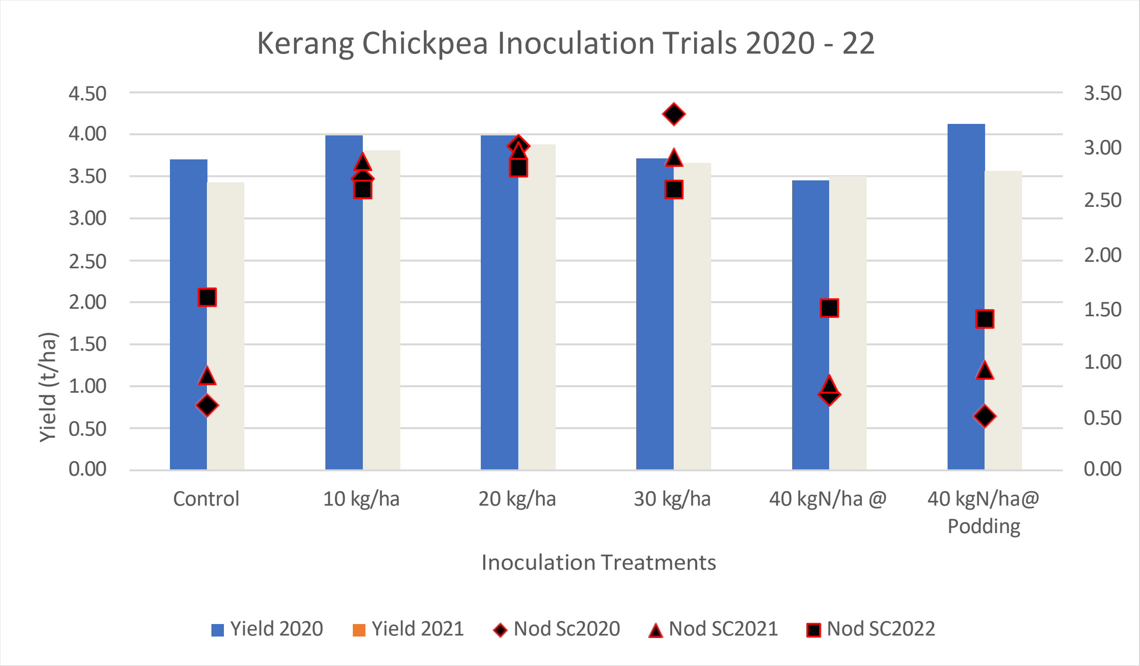


***Figure 2**: Yield (t/ha) and Nodulation Score (Nod Sc) from the Kerang 2020 - 2022 trials.*

Inoculation saw significant improvement in nodulation scores assessed nine weeks after sowing. However, the grain yields have not followed a similar trend, with yields regarded as statistically similar.

Disease management in irrigated chickpeas

Key point summary

- Chickpeas have been more susceptible to foliar disease, specifically ascochyta, than faba beans at both research sites.
- The disease rating of the cultivar was an important indicator of cultivar yield performance.
- Disease pressure was low in 2020 and extreme in 2022 and was reflected in the level of disease and the cultivar response.
- The benefit of an 'Expensive' strategy using a combination of SDHI (group 7) and QoI (Group 11) chemistry gave significantly better disease control than a 'Cheap' strategy based on chlorothalonil with PBA Monarch at both sites in 2021 and 2022.
- Yield reflected the level of disease control in both cultivars.
- Under extreme disease pressure in 2022, the 'expensive' strategy required treatment every three weeks from late July until October to keep disease suppressed at Kerang.
- While the untreated yields at Kerang in 2021 were approximately 50% of those yields where disease was controlled, the actual grain produced was unlikely to have any commercial value due to the number of small and discoloured chickpeas in the untreated sample.

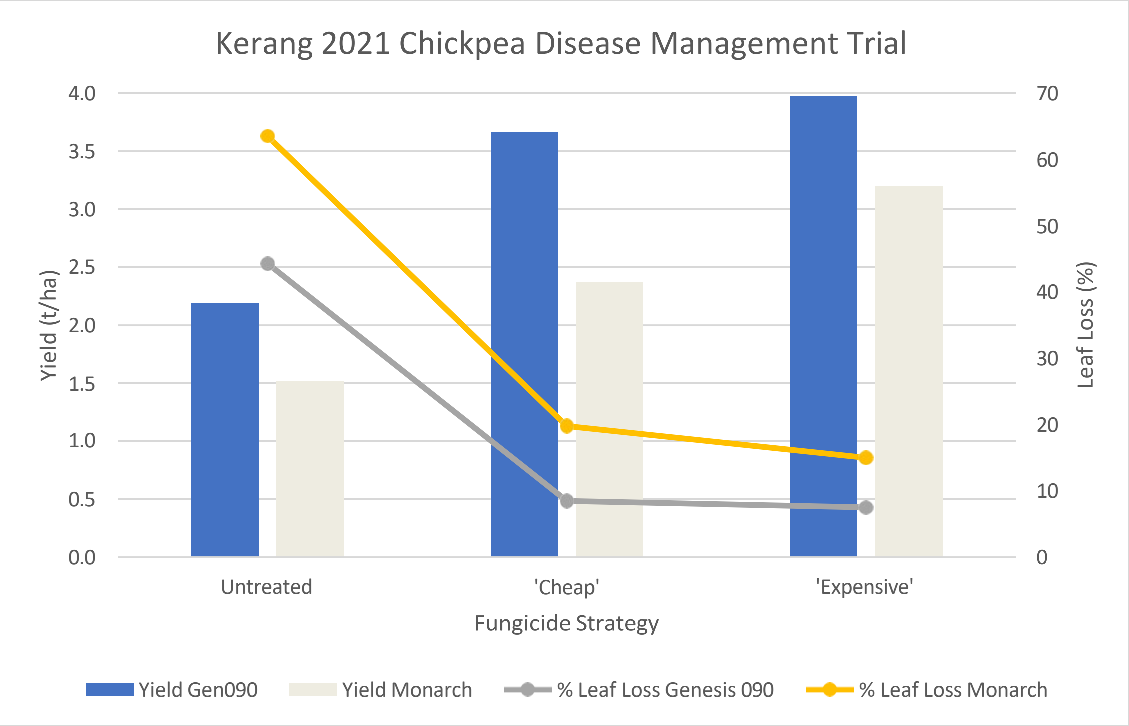


Figure 3a: *Yield (t/ha) and Leaf Loss (% leaf area lost) in two chickpea cultivars at Kerang 2021.*

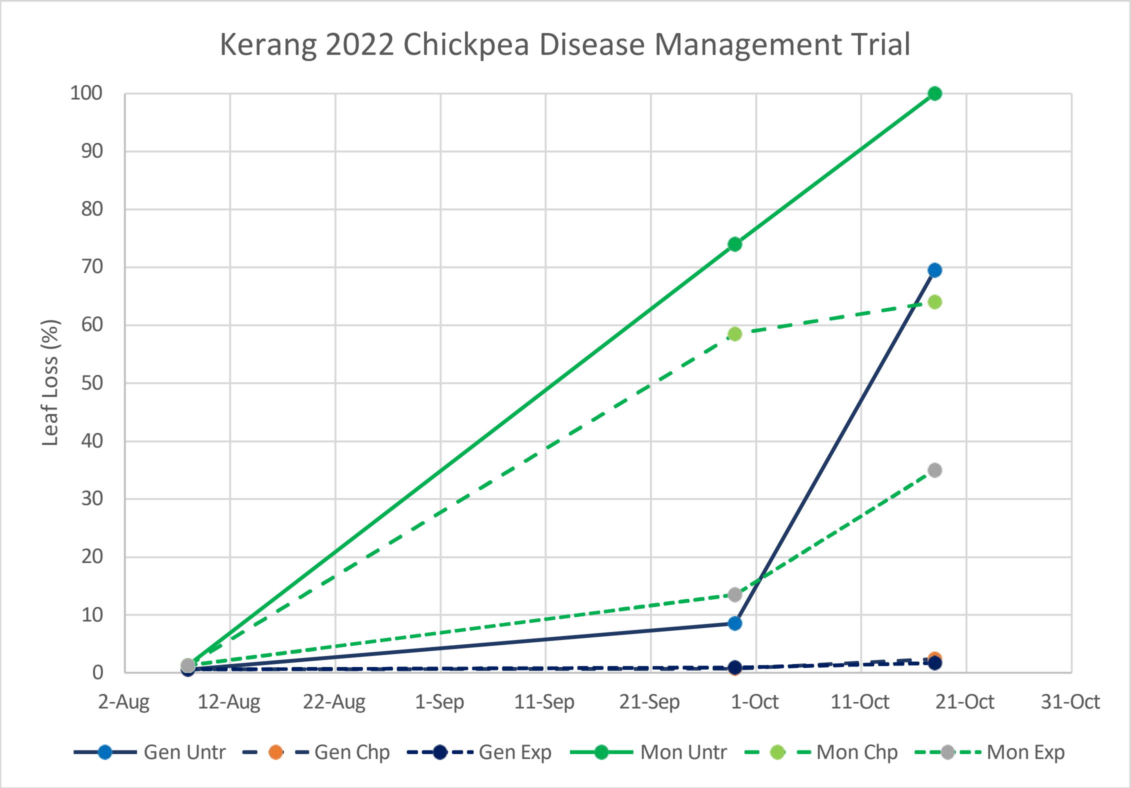


Figure 3b*: Leaf loss in two chickpea cultivars in a high disease pressure year 2022 (No harvest was possible due to inundation).*

4.5 DURUM

Nitrogen (N) strategy for yield and quality

Key point summary

- The ability to use irrigation to improve the efficiency of later N timings is ideal for producing a crop that requires high protein levels to achieve the grade required.
- Results illustrated that later N timings of main N doses in durum maintain yield potential whilst at the same time giving high proteins.
- The ability to delay all of the N until GS32 (second node) and GS37 (flag leaf just visible) will need to be considered in the light of available soil N in the profile at late tillering and GS30.
- Very low levels of soil N available at GS30 may require a small late tillering dose in order to feed the crop (40N). With high levels of available soil N this can be delayed until GS32.
- In 2020 at Finley, high soil fertility (232kg N/ha in the 0-90cm soil profile at sowing) resulted in no response to applied N fertiliser, with no significant difference in grain yield between 28-378kg N/ha applied.
- In a scenario of lower soil fertility in 2021 (measured 47kg N/ha in the soil, 0-90cm, 23rd August), increasing applied N rates (Urea 46% N) from 0-350kg N/ha had no significant effect on grain yield above 100kg N/ha, but to be certain of having 13% grain protein for DR1, N levels had to be increased to 200kg N/ha since 150kg N/ha achieved only 12.5% grain protein.
- A separate adjacent nitrogen timing trial demonstrated that protein above 13% could be achieved with 100kg N/ha by delaying the timing to GS32 and GS37 (Table 1).
- The same trials at Kerang (2020 & 2021), with starting soil N 77-130 kg N/ha, showed that maximum yield was achieved with N rates of 100-200kg N/ha and 13% protein could be achieved with no more than 200kg N/ha if timing was delayed to GS32 & GS37.

Durum has been an important crop in the OIG research programme over the three years of the project. The research covered all aspects of agronomy, but nutrition was a key component of the work. How can we reliably achieve 7t/ha plus with protein levels that meet the 13% level? Work was centred on N rates and N timing. In 2020 high residual soil N (232N-0-90cm profile) built up from the drier previous seasons resulted in no yield response for N applied above starter N (28N). In 2021 soil available N was much lower at the start of spring (47N 0-90cm) and there were yield responses up to 100kg N/ha with 13% grain protein achieved at 200kg N/ha applied (Figure 1). A separate adjacent nitrogen timing trial demonstrated that protein above 13% could be achieved with 100kg N/ha by delaying the timing to GS32 and GS37 without sacrificing yield. (Table 1). At both Kerang and Finley similar findings were identified with regards to later N timings under surface and overhead irrigation whereby later N timings gave the optimum combinations of yield and grain protein.

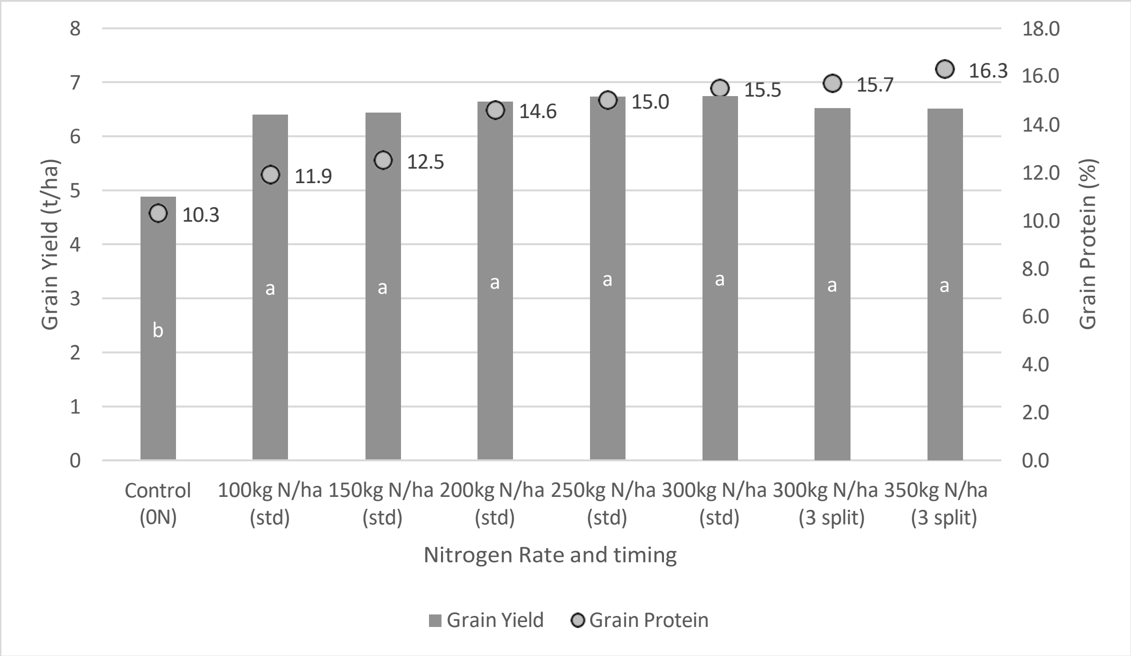


Figure 1. *Influence of applied nitrogen at stem elongation on grain yield (t/ha) and protein content (%). – Finley 2021 Notes. Std – nitrogen split 50:50 between GS30 and GS32. 3 split – 100kg of nitrogen withheld until GS39 with the remainder split 50:50 between GS30 and GS32. Yield bars with different letters are considered statistically different.*

Table 1. *Influence of N rate and timing strategies on grain protein (%) based on split application rates (0-300kg N/ha).*

	Nitrogen Application Rate				
	0kg/ha N	**100kg/ha N**	**200kg/ha N**	**300kg/ha N**	**Mean**
Nitrogen Timing	**Protein %**	**Protein %**	**Protein %**	**Protein%**	**Protein%**
PSPE & GS30	10.9 -	12.4 -	13.8 -	15.0 -	**13.0 b**
GS30 & GS32	10.6 -	12.5 -	13.7 -	15.0 -	**13.0 b**
GS32 & GS37	10.9 -	13.4 -	15.3 -	16.4 -	**14.0 a**
Mean	**10.8 d**	**12.8 c**	**14.3 b**	**15.5 a**	
N Timing		LSD	0.4	**P val**	<0.001
N Rate		LSD	0.5	**P val**	<0.001
N Timing x N		LSD	ns	**P val**	**0.235**

Soil N available – 47kg N/ha 0-90cm

Crop lodging control and use of PGRs

Key summary points:

- Aurora durum is prone to greater lodging problems during grain fill than Vittaroi.
- PGR applications at Finley and Kerang in 2020 and 2021 in Aurora consistently resulted in a reduction in both crop height and lodging during grain fill.
- At Kerang in 2021, treatments where Moddus at 200ml/ha and Errex at 1.3l/ha were applied at various timings gave an average yield increase of 1.97t/ha over the untreated control plots (Table 1).

Four trials were conducted at two sites (Finley and Kerang) over two years (2020 and 2021). Moddus Evo mixed with Errex and an unregistered experimental product were used at various rates and timings. A grazing treatment was added where plots were mowed (mechanical defoliation) twice (GS22 and GS30) to simulate grazing. Responses to plant growth regulator (PGR) chemicals resulted in a reduction in crop height and reduced lodging. The yield results varied from 0-2.04t/ha. In most cases grazing led to a reduction in lodging, however it almost always led to a reduction in yield compared to the highest yielding plots in each trial. Table 1 illustrates the trial where the biggest penalty to not using a PGR occurred.

Table 1. *Influence of PGR strategy on Grain yield (t/ha) and crop height - Kerang 2020 cv Aurora.*

PGR Treatment			**Grain yield and quality**			
			Yield		**Plant Height**	
No.	**Product and Rate**	**Timing**	**t/ha**		**cm**	
1.	Untreated		7.61	d	100	a
2.	Moddus Evo 200mL/ha + Errex 1.3L/ha	GS31-32	9.49	ab	83	ef
3.	Moddus Evo 100mL/ha + Errex 0.65L/ha Moddus Evo 100mL/ha + Errex 0.65L/ha	GS30 GS32	9.59	ab	81	f
4.	Errex 1.3L/ha Moddus Evo 200mL/ha	GS30 GS32	9.65	a	86	de
5.	Errex 0.65L/ha Moddus Evo 100mL/ha	GS30 GS32	8.17	cd	98	ab
6.	Moddus Evo 200mL/ha + Errex 1.3L/ha FAR PGR 20/01 0.75 L/ha	GS31-32 GS39	9.64	a	81	f
7.	Moddus Evo 100mL/ha + Errex 0.65L/ha Moddus Evo 100mL/ha + Errex 0.65L/ha FAR PGR 20/01 0.75 L/ha	GS30 GS32 GS37	8.95	abc	84	ef
8.	FAR PGR 20/01 0.75 L/ha	GS39	7.81	d	98	ab
9.	Grazing (twice GS22 & GS30)	GS22 & GS30	8.61	abcd	91	cd
10.	FAR PGR 20/01 0.75 L/ha + Errex 1.3 L/ha	GS32	8.53	bcd	95	bc
	Mean		**8.81**		**89.7**	
	LSD		1.08		4.52	
	P val		0.001		<0.001	

Disease management in durum

Key point summary

- Over three years of trials stripe rust caused by the pathogen Puccinia striiformis has been a key aspect of growing DBA Vittaroi and flutriafol used upfront in furrow has been an effective starting point for growing a disease-free crop.
- Key foliar fungicide follow-ups to flutriafol applied GS39 (flag leaf fully emerged) have frequently been the most profitable way to manage stripe rust in a susceptible durum crop.
- If the period from flag leaf to head emergence is wetter than normal for your region, consider an extra foliar spray at head emergence to the protect the head and "top up" disease control in the upper leaves.

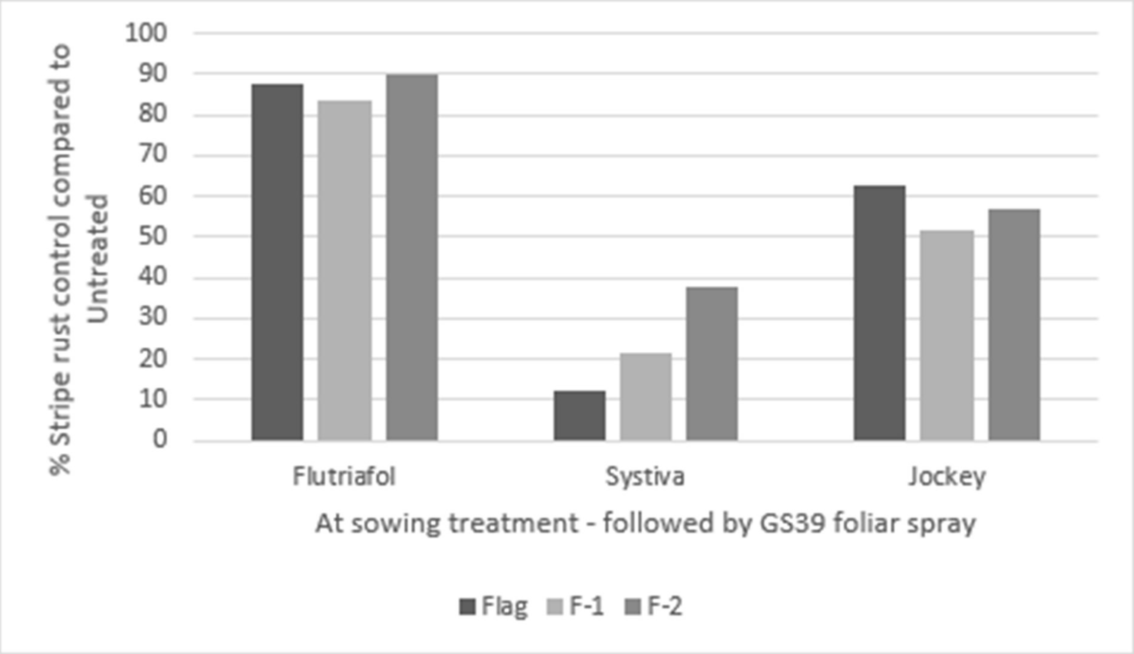


Figure 2. *Influence of "at sowing" seed treatment and in furrow fungicides for stripe rust control compared to control – assessed 23 September at GS49. Prosaro 300ml/ha applied at GS39 across all treatments.*

4.6 FABA BEANS

Crop structure and Plant population

Key point summary

- High yielding faba bean crops greater than 7t/ha are achievable under both overhead and surface irrigation systems.
- The penalty for growing faba bean crops that are too thin is significant under irrigation.
- Aiming for populations above the optimum is less risky, with little to no penalty for canopies that are above optimum.
- Despite slower sowing speeds, the profitability of higher seed rates was still advantageous.
- With plot yields varying from 2.5t/ha to 8t/ha, the older variety Fiesta VF consistently out yielded the newer variety PBA Amberley by 8%.
- Surface irrigation combined with growing season rainfall at both Finley and Kerang was at least 500mm in order to achieve 7t/ha plus.
- Overhead irrigation systems in 2020 associated with 400mm of GSR and irrigation combined produced only 4-5t/ha with lower pod numbers/m2 and harvest dry matter.
- With a very wet spring and little or no need for irrigation in 2022 responses to disease control were the highest observed in the project.
- However other than the extreme conditions of 2022 disease control responses in irrigated crops have not typically been as high as those observed in the high rainfalls further south.

Cultivar and Population

Fiesta out yielded PBA Amberley by 8% across the two years of research trials when irrigation was required. This increased yield was consistent over plant populations that varied from low to high density, however at the high populations (plus 40 plants/m^2) PBA Amberley appeared to drop in yield slightly.

Irrigated grain yield plateaued at around 30 plants/m^2 and there was little gained going above 25 plants/m^2. However, when plant populations started to drop below 20 plants/m^2 the yield loss was significant. With higher yield potentials under irrigated cropping systems, the small drops in plant populations have a “magnifying” effect on grain yield loss (loss of approx. 1.5t/ha when dropping from 20 to 10 plants/m^2). In contrast, moving from 20-30 plants/m^2 increased yield by 0.5t/ha and whilst higher populations were rarely higher yielding, the risk of poorer yield performance was very slight in comparison to populations dropping below the optimum.

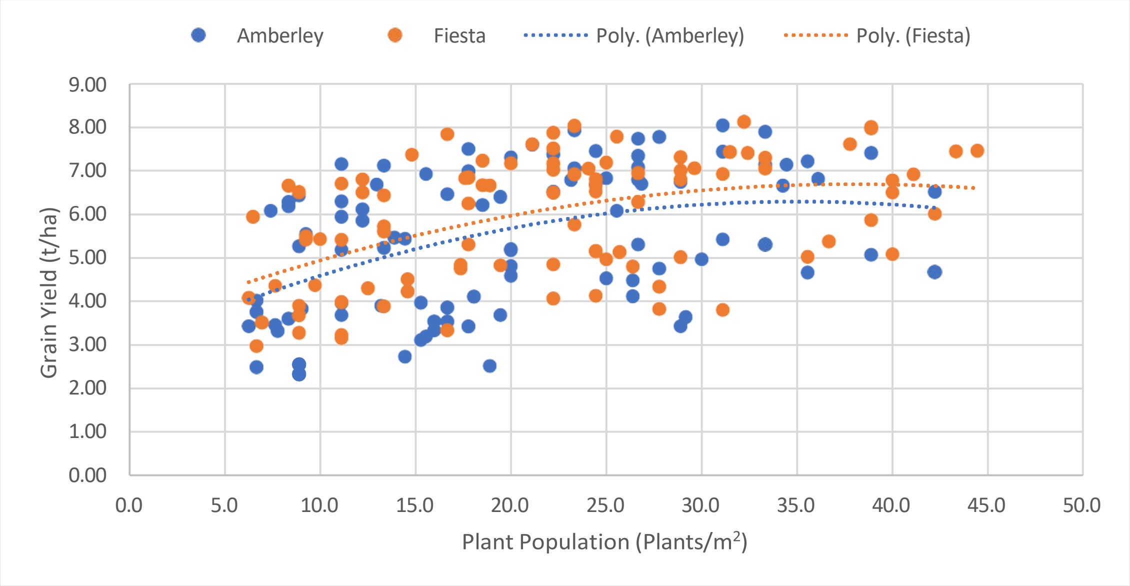


Figure 1. *The influence of faba bean plant populations on grain yield (t/ha). Data points from six trials across two years (2020 & 2022) and two sites (Finley and Kerang).*

If aiming for 20 plants/m^2, there are greater negative consequences if populations fall below that target than where populations are higher than the target, even up to 35-40 plants/m^2. Therefore, there is less risk of losing yield if aiming for higher populations (25-30 plants/m^2) than falling short.

Economics of higher seed rates

12 trials tested faba bean seed rates and plant populations over the three years of the project. These trials covered two sites, two cultivars, two irrigation types and 4 seed rates (plant populations) each year. The average yield for each seed rate across all these trials is shown in the table below. Yield increases with increasing seed rate even up to the maximum tested of 48 seeds/m^2, but growers need to know if it is economically feasible to increase seed rates. Apart from the cost of extra seed, one of the issues with increased seed rates is the ability of the seeding equipment to handle higher seed rates. The seed rates (seeds/m^2) below have been converted into sowing rate (kg/ha) based on an average seed size of 580g/1000seeds. A conservative estimate has been made that a seeder can sow up to 100kg/ha effectively, and for sowing rates above this one would need to slow down proportionally as seed rate increases. Effectively, sowing at 200kg/ha will be half the normal work rate and subsequently the contractor fee per hectare has been doubled. Using a combination of contract seeding fees and seed costs, the net income has been calculated for each seed rate.

Table 1. Influence of faba bean seed rate and plant population on yield (t/ha) and economics ($/ha).

Seed Rate	**12 seeds/m^2**	**24 seeds/m^2**	**36 seeds/m^2**	**48 seeds/m^2**
Seed rate (kg/ha)	70	140	210	280
Yield (t/ha)	3.4	4.4	4.8	5.0
Seed Price @ $500/t	$ 35.00	$ 70.00	$ 105.00	$ 140.00
Gross income @ $370/t	$ 1,273.67	$ 1,626.25	$ 1,776.41	$ 1,837.41
Contract rate ($/ha)	$ 60.00	$ 84.00	$ 126.00	$ 168.00
Total Seeding Costs	$ 95.00	$ 154.00	$ 231.00	$ 308.00
Net Income	**$ 1,178.67**	**$ 1,472.25**	**$ 1,545.41**	**$ 1,529.41**

Using a combination of contract seeding fees and seed costs, the margin over input cost has been calculated for each seed rate and compared to the standard seed rate of 12 seeds/m^2.

***Table 2.** Return on investment (ROI) ($/ha, %) from incremental increases in faba bean plant populations.*

Seed Rate	**12 seeds/m^2**	**24 seeds/m^2**	**36 seeds/m^2**	**48 seeds/m^2**
Extra cost cf. 12 seed/m^2	$ -	$ 59.00	$ 136.00	$ 213.00
Extra income cf. 12 seed/m^2	$ -	$ 352.58	$ 502.74	$ 563.74
Net margin	$ -	$ 293.58	$ 366.74	$ 350.74
ROI		**498%**	**270%**	**165%**

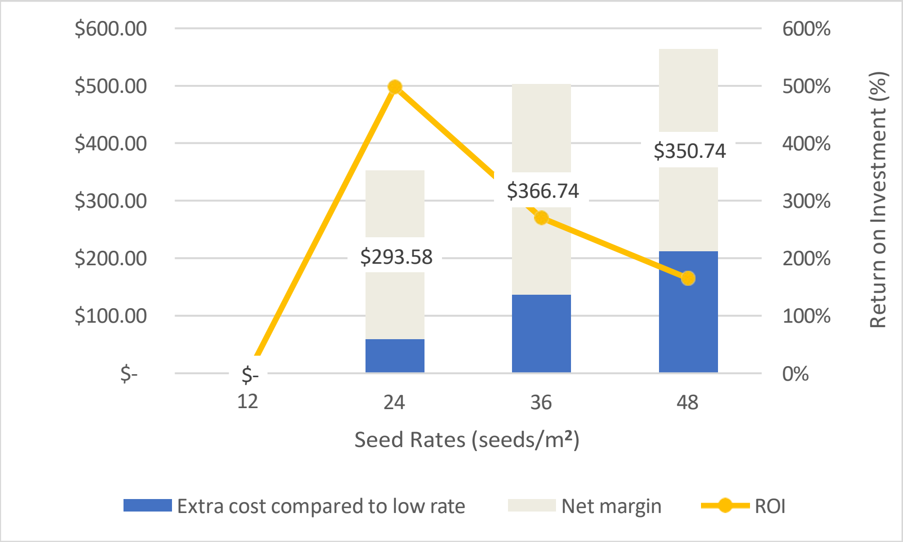
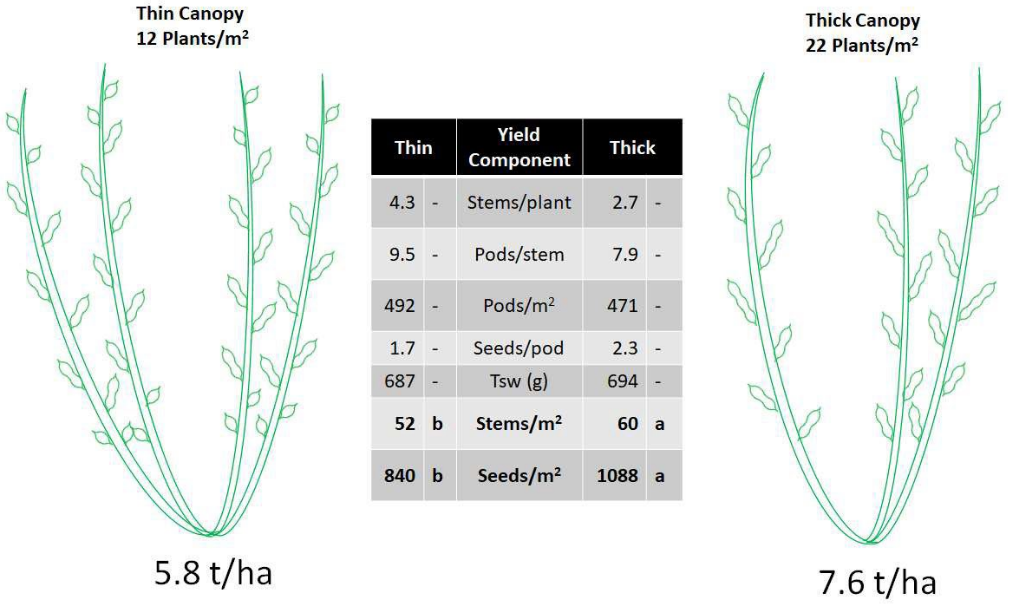


Figure 2. *Extra input costs, net margin ($/ha) and return on investment (ROI) of higher seed rates, compared to 12 seeds/m^2 (set at $0 for comparison purposes).*

What makes a 7-tonne faba bean crop?

This illustration has been based on analysis of faba bean crops in the OIG project yielding over 7t/ha compared to crops with lower yields to illustrate where additional yield comes from.



Thin		Yield Component	Thick	
4.3	-	Stems/plant	2.7	-
9.5	-	Pods/stem	7.9	-
492	-	Pods/m^2	471	-
1.7	-	Seeds/pod	2.3	-
687	-	Tsw (g)	694	-
52	**b**	**Stems/m^2**	**60**	**a**
840	**b**	**Seeds/m^2**	**1088**	**a**

Nitrogen Fixation

Key point summary

- Using current estimates, high yielding faba bean crops are removing more nitrogen in the grain than they are supplying in nitrogen fixation.

Current rules of thumb (for dryland bean crops) for nitrogen fixation are 20kg of N fixed per tonne of dry matter biomass at flowering and estimates of nitrogen removal are based on 40kg of N per tonne of grain.

Using these estimates, our irrigated faba bean crops are removing up to 300kg N/ha while only supplying 110-190kg N through fixation leaving a large N deficit.

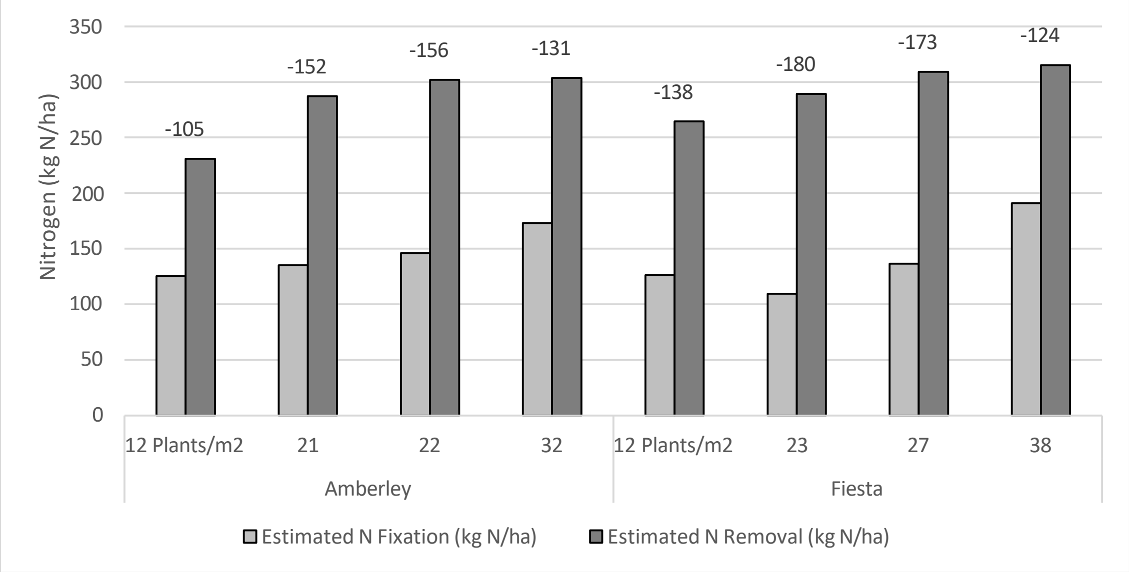


Figure 3. *Estimates of nitrogen fixation and removal from high yielding irrigated faba bean crops. Data labels show the nitrogen deficit.*

Disease management in faba beans

Key point summary

- Irrigated faba beans have not been as responsive to disease management as crops grown under high growing season rainfall conditions, illustrating that irrigation has not created the same conditions for infection as crops exposed to frequent rainfall events such as 2022.
- Of the three years (2020 – 2022), evaluated disease as a result of chocolate spot caused by the pathogen Botrytis fabae was most problematic in 2022 when little or no irrigation was applied to the crop.
- When the flowering and the early pod fill period are subject to wet weather (as opposed to irrigation under bright sunny drying conditions), greater persistence needs to be considered for fungicide inputs either by virtue of more fungicide applications, higher rates or more effective fungicides (SDHI based applications) such as Miravis® Star based on the SDHI pydiflumetofen or Aviator Xpro based on the SDHI bixafen).

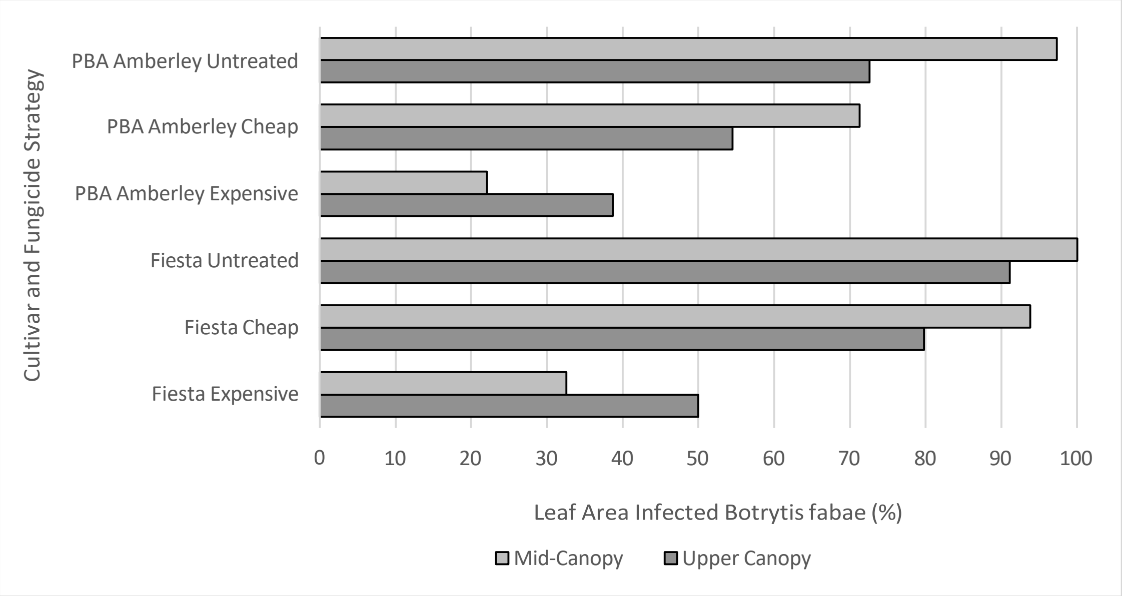
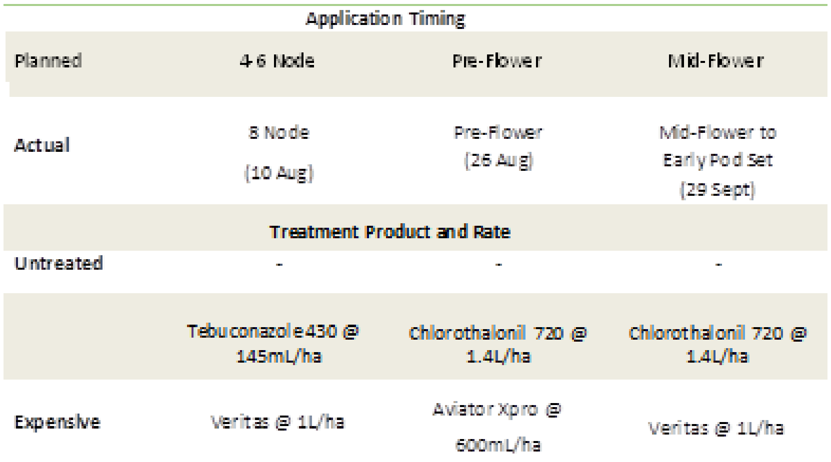


Figure 4. *Influence of fungicide strategy on chocolate infection severity during pod set in the mid and upper canopy – Finley, NSW 2022.*

Notes on fungicide application in 2022 are laid out.

Table 2. *2022 Fungicide treatments and timings on faba beans – Finley, NSW 2022.*



	Application Timing		
Planned	4-6 Node	Pre-Flower	Mid-Flower
Actual	8 Node (10 Aug)	Pre-Flower (26 Aug)	Mid-Flower to Early Pod Set (29 Sept)
	Treatment Product and Rate		
Untreated	-	-	-
	Tebuconazole 430 @ 145mL/ha	Chlorothalonil 720 @ 1.4L/ha	Chlorothalonil 720 @ 1.4L/ha
Expensive	Veritas @ 1L/ha	Aviator Xpro @ 600mL/ha	Veritas @ 1L/ha

Table 3. *Influence of fungicide strategy faba bean grain yield (t/ha) – Finley, NSW 2022.*

	Yield t/ha					
Fungicide Strategy	**PBA Amberley**		**Fiesta VF**		**Mean**	
Untreated	2.45	cd	2.04	d	**2.25**	**c**
Cheap	2.62	cd	3.00	bc	**2.81**	**b**
Expensive	3.36	b	4.14	a	**3.75**	**a**
Mean	**2.81**	**-**	**3.06**	**-**		

Cultivar	**LSD p=0.05**	ns	**P val**	0.160
Fungicide Strategy	**LSD p=0.05**	0.41	**P val**	<0.001
Cultivar x Strategy	**LSD p=0.05**	0.58	**P val**	0.025

5.0 Regional Results

The OIG project has covered irrigated crop research in other regions. This research has been based on a much smaller number of trials over the same three-year period. The following section carries some of the key points from this research.

5.1 Spring sown barley (Tasmania)

The irrigated cropping studies in Tasmania have centred on spring sown barley which has proven to be a very profitable low input crop if grown with attention to detail in terms of establishment and timeliness of inputs. The trials have taken place at Hagley in the North Midlands of Tasmania and have been carried out under overhead irrigation with a moving lateral.

Key point summary

- Spring sown barley on the mainland is vulnerable to drier late spring/summer conditions and higher temperatures during its critical periods of development.
- In Tasmania however the higher temperatures are less constraining to yield performance compared to the mainland and spring barley under irrigation can be grown very successively.
- In addition, compared to the same crop sown in the autumn it can be grown with much lower inputs, particularly the fungicide input, with lower label rates being just as effective due to lower disease pressure.
- Project trials have shown yields in excess of 10t/ha grown on chromosol soils as part of a cropping rotation where establishment takes place in early September with harvest in early February.
- In terms of nutrition and indeed all inputs, it is important to recognise that when the crop starts to grow in spring it moves through its development stages far quicker than equivalent autumn sown crops.
- With regards to nutrition, it is a relatively low input crop if grown for malt with typically no more than 100kg N/ha required.
- As the crop grows so fast there is little disadvantage having all N fertiliser input completed by the three-leaf stage (GS13), although with a good soil nitrogen reserve response to nitrogen can be limited to less than a 100kg N/ha.
- With a soil N reserve of 165kg N/ha in early spring (0-60cm), in 2022 there was no yield response to applied N fertiliser, with 200kg N/ha of applied nitrogen only serving to push protein over 12% and out of the malting range.

Spring barley sown in the spring develops very quickly and is not subject to the colder winter weather patterns. As result it does not develop the same levels of foliar disease infection in comparison to autumn sown barley. At the Tasmania Crop Technology Centre run by FAR Australia and Southern Farming Systems, spring sown RGT Planet was far cleaner than mainland crop equivalent with very low levels of net blotch, the “Achilles heel” of the crop on the mainland. At this site under overhead irrigation spring sown barley reached malting specification in all three trial years of research. Crops untreated with fungicide, whilst still showing responses to fungicide application were noticeably cleaner than autumn crops. Table 1 provides an illustration of this point using the 2022/23 data from Tasmania where fungicide treatment failed to produce any significant differences in yield or quality in spring sown Planet. Figure 1 illustrates a typical fungicide response in RGT Planet sown in the autumn on the mainland – Millicent, SA.

Table 1. *Influence of fungicide application on grain yield (t/ha) and quality of spring sown barley (%, kg/HL), harvested 1 February 2023 – cv RGT Planet.*

		Grain Yield and Quality									
Fungicide Treatment (ml/ha)		Yield		Protein		Test wt		Screenings		Retention	
GS30	**GS39-45**	t/ha		%		Kg/hL		%		%	
Untreated		9.54	-	11.3	-	69.6	-	2.1	-	93.5	-
Prosaro (300)	Radial (840)	9.93	-	11.4	-	70.2	-	1.8	-	94.7	-
Aviator (416)	Radial (840)	9.60	-	11.4	-	69.6	-	1.9	-	94.1	-
FAR F1/20	Radial (840)	9.58	-	11.1	-	69.3	-	2.0	-	94.2	-
FAR F2/20	Radial (840)	10.01	-	11.3	-	69.9	-	2.1	-	94.1	-
Radial (840)	Prosaro (300)	9.45	-	11.3	-	70.1	-	1.8	-	94.6	-
Radial (840)	Aviator (416)	9.75	-	11.4	-	70.2	-	2.0	-	94.4	-
Radial (840)	FAR F1/20	9.83	-	11.5	-	69.7	-	2.2	-	93	-
Radial (840)	FAR F2/20	9.62	-	11.3	-	70.1	-	1.9	-	94.2	-
Mean		9.7		11.3	-	69.8	-	2.0	-	94.1	-
LSD		ns		ns		ns		ns		ns	
P Val		0.62		0.58		0.26		0.80		0.16	

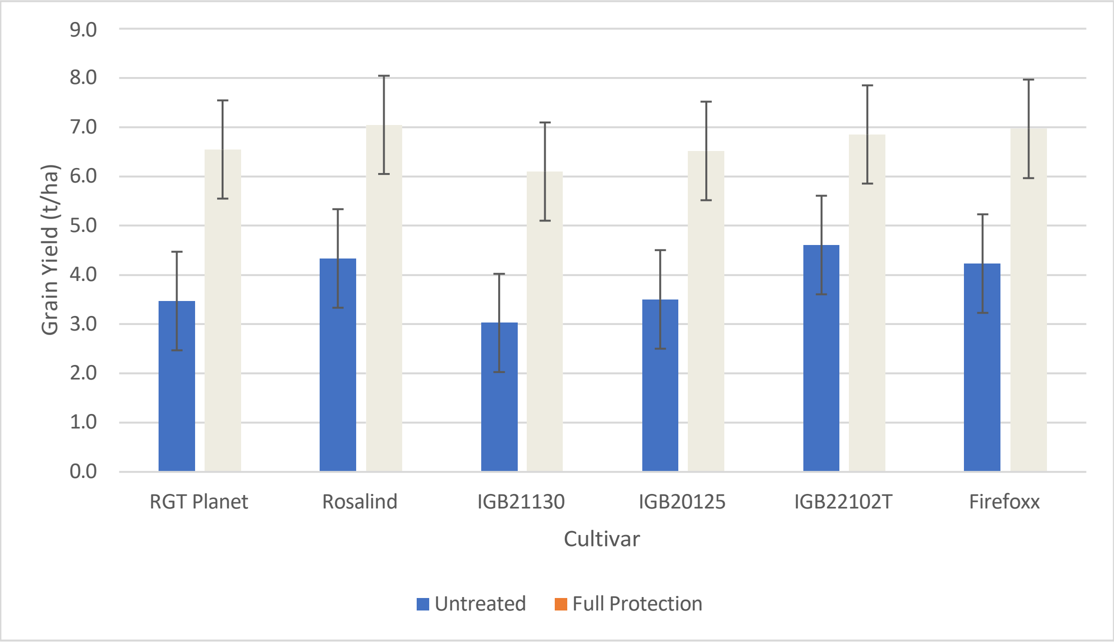


Figure 1. *Influence of fungicide management and cultivar on yield (t/ha) at the South Australian Crop Technology Centre - 2022. Error bars represent LSD (p=0.05) of 0.43. Net form Net blotch was the principal disease (Source FAR Australia GEN 2022). Fungicide treatment based 2 spray programme GS31 & GS49 (Prosaro 300mL/ha followed by Aviator Xpro 500mL/ha).*

Spring barley has been grown on the mainland as part of the OIG project, in particular to look at productivity for late sown barley in southeast SA. This research work conducted by SARDI illustrated little response to applied inputs and the difficulty of achieving anything more than feed grain specification. However, in 2022 the December sown crop achieved yields of 3.5 – 4.5t/ha with no irrigation applied and no response to applied N over 80kg N/ha other than to increase protein. With the climatic conditions of the 2022/23 summer (milder than the norm), the results provide a fair indication of the upper end of yield potential for barley crops sown in this late window (December). (Tables 2 and 3).

Table 2. *Influence of nitrogen rate and timing strategy on grain yield – RGT Planet, Coonawarra, SA.*

	Yield t/ha				
Application Timing	**0kg N/ha**	**80kg N/ha**	**160kg N/ha**	**240kg N/ha**	**Mean**
GS00 & GS23	3.71 -	4.06 -	3.73 -	3.56 -	3.76 -
GS23 & GS30	3.52 -	4.20 -	3.75 -	3.26 -	3.68 -
GS30 & GS33	3.82 -	4.51 -	3.96 -	3.54 -	3.96 -
Mean	3.68 bc	4.25 a	3.81 b	3.45 c	

N Timing	LSD p=0.05	ns	P val	0.290
N Rate	LSD p=0.05	0.31	P val	<0.001
N Timing x N Rate	LSD p=0.05	ns	P val	0.871

Table 3. *Influence of nitrogen rate and timing strategy on grain protein.*

	Protein %				
Application Timing	**0kg N/ha**	**80kg N/ha**	**160kg N/ha**	**240kg N/ha**	**Mean**
GS00 & GS23	13.3 e	13.0 f	13.7 b	13.7 b	13.4 ab
GS23 & GS30	13.6 bc	13.0 f	14.1 a	13.4 cde	13.5 a
GS30 & GS33	13.0 f	13.3 e	13.5 bcd	13.4 de	13.3 b
Mean	13.3 c	13.1 d	13.8 a	13.5 b	

N Timing	LSD p=0.05	0.1	P val	0.032
N Rate	LSD p=0.05	0.1	P val	<0.001
N Timing x N Rate	LSD p=0.05	0.2	P val	<0.001

5.2 Autumn sown milling wheat (Southeast South Australia – Frances, SA)

In the second year of the project the OIG team applied for a variation to work on autumn sown wheat in the Frances region of southeast SA, since there was little interest amongst the growers in the other project crops for use under overhead pivots. The focus of the research conducted by SARDI was on nitrogen strategies for milling wheat and disease control.

Key point summary

N strategies

- Autumn sown milling wheat results in SE SA illustrated no economic benefits of exceeding 200-250kg N/ha in order to produce quality milling wheat.
- N inputs in excess of this level can produce more dry matter but are frequently associated with increased lodging and a reduction in yield as a result, particularly where starting soil N levels are above 100kg N/ha (0-60cm).
- Measuring available soil nitrogen at the end of winter prior to GS30 with cereals, or before sowing gives an indication of soil mineral N reserve, it is therefore essential to plan N strategy for both dryland and irrigated crops.
- The contrast between 2021 and 2022 results from the Frances location exemplifies the some of the difficulties with N strategies.
- In 2021 (ex lucerne hay) there was both a yield and protein response to applied N application in Rockstar, whilst in 2022 (ex canola) there was a protein response to applied N but not a significant yield response. In both years the yields were roughly similar 8 – 9t/ha.
- Looking at the crop reflectance assessments, it’s interesting to note that when all three N applications were made in 2022 (GS30, GS32 and GS39,) the plots receiving no spring top dressing had a crop canopy reflectance (measured as NDVI) which was almost identical to the fertilised plots.
- However, in 2021 by the second N application the unfertilised plots were already showing lower crop reflectance (lower NDVI readings (less crop canopy greenness)). Both trials make the case for creating small N deficient areas in commercial crops where growers can assess the availability of N in their farming systems.
- Whilst soil mineral N tests indicate what is available at the time of sampling, they do not give us a clear indication of how much N the soil will mineralise during the course of the season. Either sampling again in early spring or using the crop as a visual indicator (NDVI) enables us to better measure N being produced during the course of the season (N mineralisation).
- Whilst NDVI measurements might not specifically link to an advised N rate, it is a very useful indicator as to when N might be required if starting N levels are very high and early N doses are not required.

Disease management in irrigated wheat

- With susceptible milling wheat cultivars such as Rockstar the research has illustrated that three spray programmes incorporating fungicide timings at GS31-32 (1st- 2nd node), GS39 (flag leaf) and GS59 (head emergence) are the backbone of profitable disease management strategies.

Background trials data

The following two trials were carried by the SARDI team in southeast SA on the same cultivar over the 2021 and 2022 seasons as part of the OIG project. The results are a reminder that more and more N fertiliser is not the basis of a good, irrigated N strategy, but knowing your soil N status and using visual signals from the crop will aid in making better agronomic decisions.

2021 (Irrigation - 50mm) – GSR 339mm, Soil Mineral N - 66kg N/ha (0-90cm)

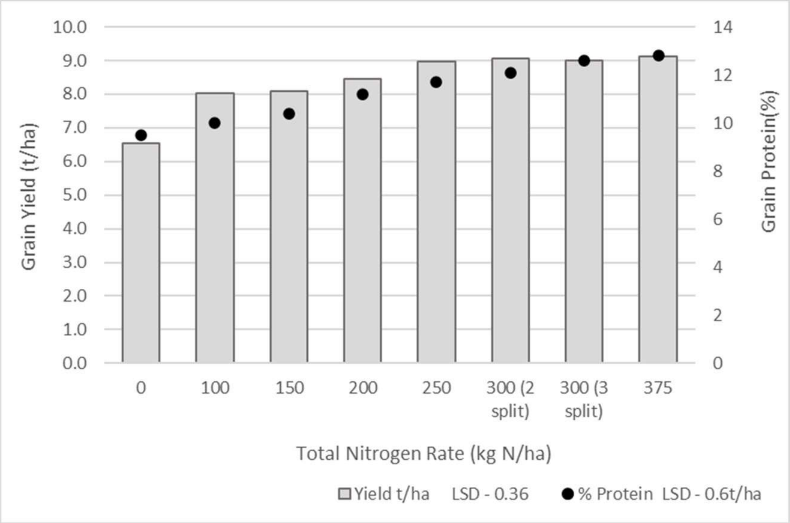


Figure 2. *Influence of N rate on grain yield (t/ha) and protein (%) - cv Rockstar ex Lucerne Hay– Frances, SA sown 20th May 2021.*

2022 (No irrigation applied) – GSR 428 mm, Soil Mineral N - 180kg N/ha (0-90cm)

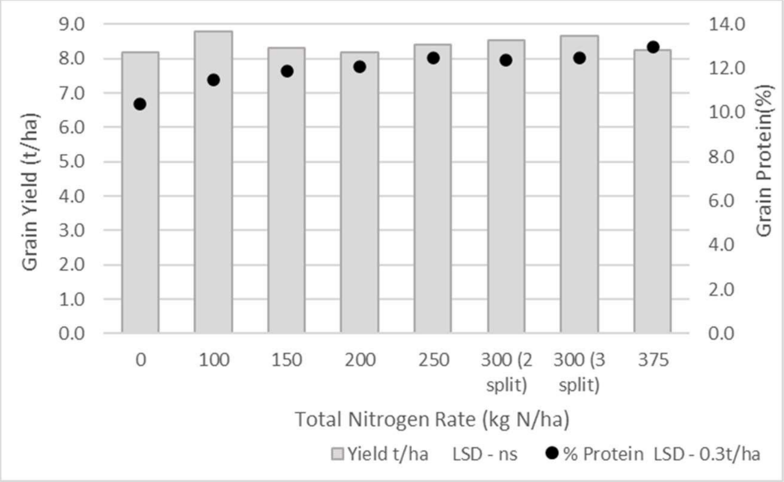
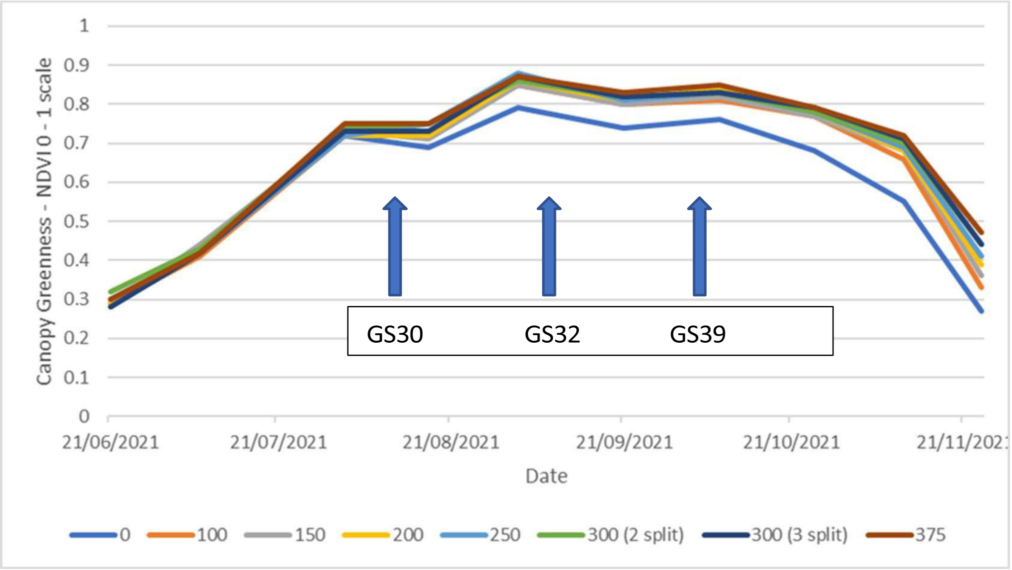


Figure 3. *Influence of N rate on grain yield (t/ha) and protein (%) - cv Rockstar ex canola – Frances, SA sown 19th May 2022.*

Both crops produced similar yields, however in 2021 the economic optimum N rate was 250kg N/ha whilst in 2022 the minimum H2 protein was obtained with only 100kg N/ha, indicating the value of the larger available N levels in the soil in 2022 compared to 2021.

The two crops did give visual signals (quantified by crop reflectance and NDVI) through the course of the season that there was greater fertility in 2022 compared to 2021. If in a commercial crop there was a small section or sections of the crop with no top-dressed N applied, then the following NDVI graphs illustrate that by the second N timing at GS32 (second node), in 2021 the crop with zero spring N applied had lower crop canopy reflectance compared to those crops that were top dressed (using NDVI). This was not the case in 2022 where the crop that received no dressed N was giving similar crop reflectance up until booting. Whilst it doesn't allow the grower to calculate the exact optimum N rate if there is little difference in NDVI between zero N applied and the first two applications, it will establish that more N at the later timings is not needed or that no difference early in the season that early N doses are not required as the soil fertility is providing nutrition needed.

2021



2022

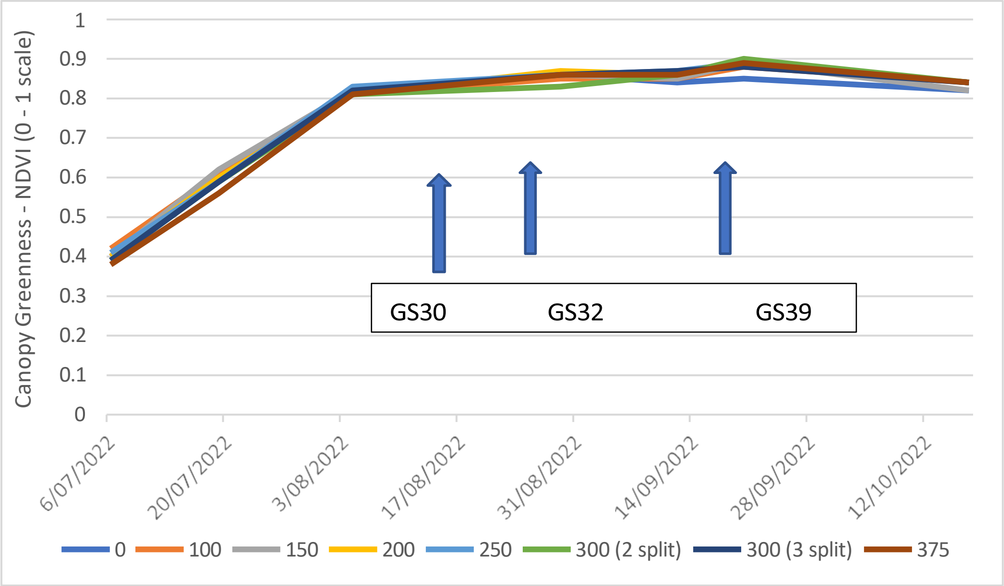


Figure 4. *Influence of applied N rates and timing on crop reflectance measured using NDVI – Frances, SA 2021 & 2022 cv Rockstar.*

Fungicide strategy – 2022 results from Frances, SA (No irrigation applied)

Table 3. Influence of fungicide strategy on grain yield and grain quality (grain protein, grain test weight and screenings).

	Grain Yield and Quality				
Fungicide Strategy	**Yield t/ha**	**Protein %**	**Test Weight kg/hL**	**Screenings %**	**Binned Grade**
Untreated	5.49 c	12.6 ab	71.7 bc	3.8 ab	AUH2
Systiva + 1 spray	5.77 c	12.4 abc	70.9 bc	4.3 a	AGP1
Jockey + 1 spray	5.69 c	12.7 a	70.7 c	3.2 abc	AGP1
Flutriafol + 1 spray	5.87 c	12.5 abc	72.0 bc	4.0 ab	AUH2
2 sprays (O + P)	7.01 b	12.2 cd	73.9 bc	2.4 bc	AUH2
2 sprays (O + A)	7.13 b	12.3 bc	73.5 bc	2.4 bc	AUH2
2 sprays (R + A)	7.28 b	12.1 cd	74.1 b	2.7 bc	AUH2
3 sprays (O + P + O)	8.31 a	11.5 f	79.7 a	1.6 c	H2
3 sprays (O + A + O)	8.25 a	11.9 de	77.9 a	1.7 c	H2
3 sprays (R + A + O)	8.13 a	11.8 ef	78.6 a	1.9 c	H2
Mean	**6.89**	**12.2**	**74.3**	**2.8**	
LSD p=0.05	0.75	0.4	3.3	1.6	
P val	<0.001	<0.001	<0.001	0.011	

Notes: Fungicide strategies based on GS39 for 1 spray foliar approaches (with different at sowing measures), 2 sprays based on GS31/32 and GS39 (O=Opus 500mL/ha, P=Prosaro 300mL/ha, A = Aviator 416mL/ha) and 3 sprays based on GS31/32, GS39 and GS59.

ACKNOWLEDGEMENTS

FAR Australia would like to place on record their grateful thanks to the Grains Research and Development Corporation (GRDC) for providing the investment for this project, in particular we would like to thank GRDC's Senior Manager Dr Kaara Klepper for her input, guidance and support in the oversight of the project.

In addition, we would like to acknowledge the collaborative support of our principal trials research partner Irrigated Cropping Council (ICC). We would also like to acknowledge all the OIG partners and collaborators in the project, University of Tasmania, Southern Growers, NSW DPI and the Maize Association of Australia, Irrigation Research and Extension Committee (IREC), Riverine Plains Inc, Southern Farming Systems, South Australian Research and Development Institute (SARDI) and MacKillop Farm Management Group

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