Hyper yielding dryland crop agronomy - key levers and their interactions

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Take home messages

- The hyper yielding crops (HYC) project has successfully demonstrated new yield benchmarks for productivity of cereals and canola in the more productive regions of Australia over the last three years.
- The HYC project results can be relevant to other lower rainfall regions in better seasons when soil moisture stress is not the overriding influence on yield potential and realisation.
- Hyper yielding cereal crops require high levels of nutrition; rotations which lead to high levels of inherent fertility and judicious fertilizer application underpin high yields and the large nutrient offtakes associated with bigger crop canopies.
- The biggest agronomic lever for hyper yielding wheat and closing the yield gap over the last three years has been the correct disease management strategy which had elevated importance in the very wet conditions of 2022 in all regions.
- At Katamatite in Victoria, fungicide application in Scepter⦹ based on two fungicides increased yield by over 100% (up to 2.39t/ha) through the correct product choice and up to 2.75t/ha through the incorporation of a third fungicide application.

Hyper yielding crops research and adoption

The Hyper Yielding Crops (HYC) project with assistance from three relatively mild springs has been able to demonstrate new yield boundaries of wheat, barley and canola both in research and on commercial farms in southern regions of Australia with higher yield potential. Five HYC research sites with associated focus farms and innovation grower groups have helped establish that wheat yields in excess of 11t/ha are possible at higher altitudes in southern NSW (Wallendbeen), in the southern Victoria and South Australia high rainfall zones (HRZ) (Gnarwarre and Millicent) and Tasmania (Hagley). In the shorter season environments of WA, 7-9t/ha has been demonstrated at FAR's Crop Technology Centres in Frankland River and Esperance.

Most crops grown in the Australian grain belt are traditionally yield limited by water and/or nitrogen (Angus and Grace, 2016; Hochman and Horan, 2018). This is traditionally the case in the low - medium rainfall regions of northern Victoria and southern NSW. However, in 2022 many crops were not limited by lack of growing season rainfall, but by solar radiation and temperature, a feature more commonly associated with HRZ environments. The Photothermal Quotient (PTQ) or 'Cool Sunny Index' is a simple formula (daily solar radiation/average daily temperature) that describes how conducive conditions are for growth. In the HRZ where moisture stress is less significant in defining yield potential, it is used to describe growth in the critical period for yield formation (e.g., 3-

week period prior to flowering in cereals). In 2022 solar radiation was significantly lower than average, whilst temperature during the critical period prior to flowering was in the main average. The net effect in 2022 was that even at locations traditionally limited by soil moisture, lower yield potential was set by solar radiation and temperature rather than water limited potential (Table 1).

Table 1. Selected Southern Australian sites and calculated water limited potential yield (WLpY) and photothermal quotient yield potentials (PTQpY) for 2022. Shaded cells indicate sites where the PTQpY limited yield and unshaded area where water limited yield.
(PTQ yield potential [PTQpY] is based on Peake and Angus 2009 and calculated as PTQyP = 10.099*PTQ-4.3053. Water limited potential yield (WLpY) is based on Angus and Sadras 2006 and is calculated by = estimated transpiration x 25kg grain/ha/mm. Estimated transpiration [mm] is calculated by stored soil water pre-sowing + growing season rainfall [mm] – 60 [mm] for soil water evaporation).

Site (nearest town)	Estimated Water supply (mm)	Water limited potential yield (WLpY, t/ha)	Assumed flowering date	Photothermal quotient yield potential (PTQpY, t/ha)
Hart (SA)	377	9.4	20-Sep	10.0
Kingscote (SA)	378	9.5	28-Sep	7.1
Walpeup (Vic)	394	9.9	11-Sep	8.6
Bordertown (SA)	407	10.2	7-Oct	8.3
Cummins (SA)	411	10.3	15-Sep	7.9
Charlton (Vic)	436	10.9	23-Sep	8.7
Giles Corner (SA)	457	11.4	17-Sep	10.5
Spalding (SA)	468	11.7	25-Sep	11.5
Longerenong (Vic)	552	13.8	7-Oct	9.0
Inverleigh (Vic)	564	14.1	20-Oct	9.9
Yarrawonga (Vic)	582	14.6	28-Sep	8.5
Hamilton (Vic)	627	15.7	25-Oct	9.9
Millicent (SA)	647	16.2	30-Oct	9.7
Hagley (TAS)	700	17.5	10-Nov	11.5

Yield potential at the Wallenbeen NSW HYC site in 2022

Over the last three years, the relative absence of soil moisture deficit stress at HYC locations has allowed the project team to look more closely at yield potential from the perspective of solar radiation and temperature. So how does the combination of solar radiation and temperature result in high yielding crops? **High yielding crops of wheat and barley are about producing more grains per unit area.** This has been demonstrated in several projects and is a key factor in producing very high yields. Whilst head number clearly contributes to high yields, there is a limit to the extent to which head number can be used to increase yields.

So how do we increase grains per m^2 and what is the connection to Photothermal Quotient (PTQ) or the 'Cool Sunny Index'?

Wheat grain yield (t/ha) is calculated by head/m^2 x grain number per head x weight (g) of 100 grain /10,000. Whilst more heads/m^2 contribute primarily to yield outcomes in many Australian environments (Zhang et al 2007), once this is satisfied it is typically larger numbers of grains per head at harvest that generates high yields and increases the overall number of grains per unit area in HRZ regions. It's been acknowledged for several years that increasing grain number is related to growing conditions prevalent in the period from mid-stem elongation to start of flowering (approximately GS33 – 61). This window of growth in cereals covers the period approximately three – four weeks (~300 ^{0}C. days) prior to flowering and is described as the 'critical period' (Dreccer et al 2018). This critical period encompasses when the grain sites are differentiating and developing male and female parts of the plant (meiosis). If prevailing conditions during this period of development are conducive to growth with high solar radiation and relatively cool conditions (avoiding heat stress), then more growth goes into developing grain number per head and therefore per unit area for a given head population. The Photothermal Quotient (PTQ) or 'Cool Sunny Index' describes how conducive conditions are for growth and when applied to the critical period, assists in determining the yield potential. When applied to the critical period, a high PTQ means more photosynthesis for more days and more grain and more yield. The relative importance of PTQ is increased in seasons where soil moisture stress is not a factor (since soil moisture stress limits the ability of the crop to grain fill and fulfil its potential). Based on an optimum flowering date of 10 October, the PTQ for 2022 was considerably lower (PTQ 1.27) than 2021 (PTQ 1.49) at our southern NSW HYC site. Using the graphed relationship established between yield and PTQ (PTQpY = 10.099*PTQ-4.3053), it indicated that yield potential was significantly reduced in 2022 (Figure 1) and this is without taking account of the effects of waterlogging and management of the crop more generally, indicating that yield potential was much lower relative to 2021 and the long-term average.

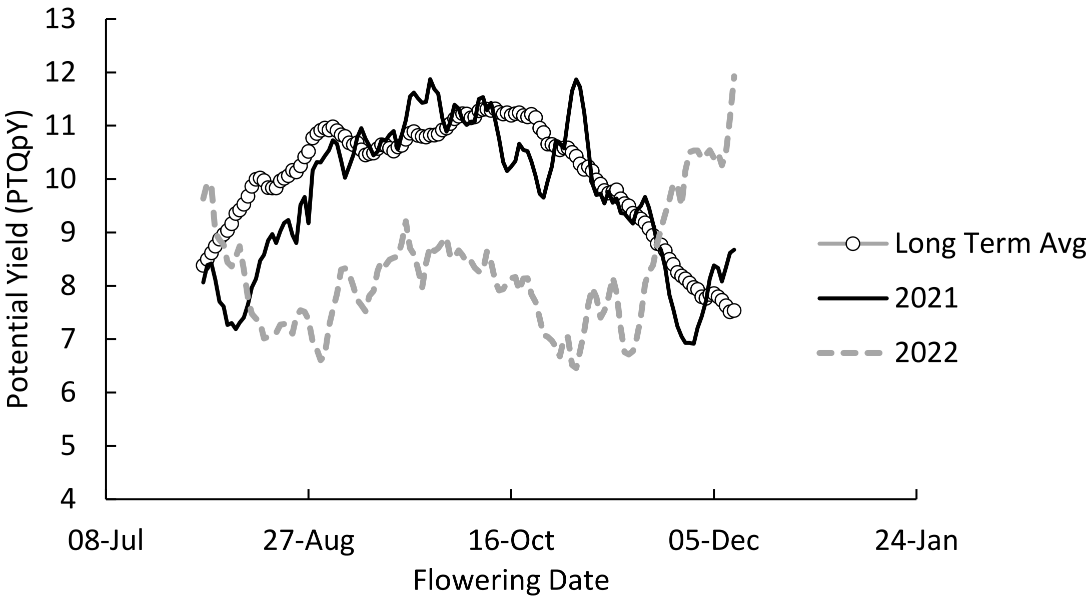

Figure 1. Long term (last 20 years based on Cootamundra BOM data) yield potential and relationship with flowering date at Wallendbeen based on the photothermal quotient (PTQ) compared to 2021, and 2022 YTD. Note this is the upper ceiling of yield potential and does not factor in frost and heat risk and assumes water is non limiting. Critical period based on 28 days in this calculation.

Advisers are already aware of the importance of cereal flowering date in order to minimise frost risk and heat stress/moisture stress, however in high yielding crops and cropping regions where moisture and heat stress are less problematic, optimising the flowering date enables us to maximise growth in the critical period for generating grain number per unit area.

Making more of better seasons in the lower rainfall regions using HYC principles

The GRDC hyper yielding crops and GRDC National Grower Network experiments in 2022 demonstrated how improved yields can be realised in lower to medium rainfall zones using management strategies more common in high rainfall zones. The importance of using increased nitrogen (N) and disease management inputs in barley to extract increased yield potential from better seasons (2022) in regions where soil moisture was not the limiting factor is highlighted below (Table 2).

Table 2. Average effect of in-crop canopy management interventions in barley across both sowing dates at the Hart and Birchip Field Sites (Nullawil) in 2022.

Canopy management interventions			2022 Hart field site SA						2022 Birchip field site Vic (Nullawil)					
Nitrogen input[1]	**Fungicide intensity[2]**	**Canopy controls[3,4]**	**Cyclops**ⓓ		**Leabrook**ⓓ		**Planet**ⓓ		**Cyclops**ⓓ		**Leabrook**ⓓ		**Planet**ⓓ	
Low	Nil	-	4.7	d	4.4	bc	5.8	jk	3.9	a	4.1	ab	4.3	bcd
Low	Low	-	5.1	fg	4.9	e	6.0	klm	4.5	de	4.8	ef	5.3	g
Low	High	-	5.6	i	5.2	gh	6.3	n	5.2	g	5.2	g	5.9	h
High	Nil	-	4.6	cd	4.4	b	5.7	ij	4.2	bc	4.4	cd	4.8	f
High	Low	-	5.6	i	5.3	h	6.5	no	5.2	g	5.2	g	5.9	hi
High	High	-	6.0	klm	5.7	ij	6.6	op	6.1	hij	6.2	ij	6.8	kl
High	High	+PGR[3]	6.1	lm	5.8	jk	6.7	op	6.3	j	6.2	hij	6.7	k
High	High	+Defoliation	6.1	m	5.9	kl	6.8	p	6.3	j	6.0	hij	7.1	l
Nil	High		4.3	b	4.1	a	5.0	ef	-		-		-	

Data with different letters are statistically different P = 0.05

Nitrogen Inputs[1]
Starting soil N supply (0 – 60cm) = 77kg N at Nullawil, and 93 kg N at Hart.
Low Nitrogen = 60kg N (Nullawil) and 55kg N (Hart) applied in season to achieve decile 3 (N inputs for a 3.5t/ha and 3.6 t/ha yield potential)
High Nitrogen = 160kg N (Nullawil), and 135kg N (Hart) applied in season to achieve decile 8 (N inputs for a 6t/ha and 5.7t/ha yield potential)

[2]Fungicide Intensity
Low = 1 x foliar fungicide unit - Prothioconazole/Tebuconazole (Prosaro 300mL/ha) @GS31
High = 4 x fungicide units - Systiva® seed treatment, 3 x foliar fungicides including QoI (strobilurin) & SDHI combinations with DMIs)

[3]Plant growth regulation (PGR) (Moddus® Evo 200 mL/ha @GS30 & Moddus Evo 200mL/ha @GS33-37). [4] Defoliation = simulated grazing @GS16 (TOS 1 & 2) and GS30 (TOS 1 only)

Nutrition and rotation for hyper yielding wheat – farming system fertility to establish yield potential

The most notable results observed in the HYC project to date relate to nitrogen fertiliser. However, simply applying high rates of N fertiliser is not always the best option to achieve hyper yields. Nitrogen fertiliser rates should consider (i) N mineralising potential of the soil, (ii) spared N from previous years, (iii) starting mineral N and other factors such as (iv) crop lodging potential that may impact radiation efficiency. It should be emphasised however that replacing N removal (N off-take in grain or hay) has to be an objective if we are to maintain a sustainable farming system. Results from our southern NSW site at Wallendbeen provide an example of the conundrum with hyper yielding wheat crops. Established in a mixed farming system based on a leguminous pasture in rotation with a cropping phase, winter feed wheat cv RGT Accrocⓓ achieved a yield of approximately 9t/ha, however the application of N above 120 kg N/ha in this scenario only served to reduce profit while higher rates ≥160kg N/ha also reduced yield (Figure 2). This confirmed a result observed in previous high yielding trials. Despite an application of PGR Moddus Evo® 0.2L/ha + Errex™ 750 at 1.3L/ha at GS31, higher applied N fertilisers increase head numbers but also increased lodging during grain fill (data not shown) which led to reduce yield.

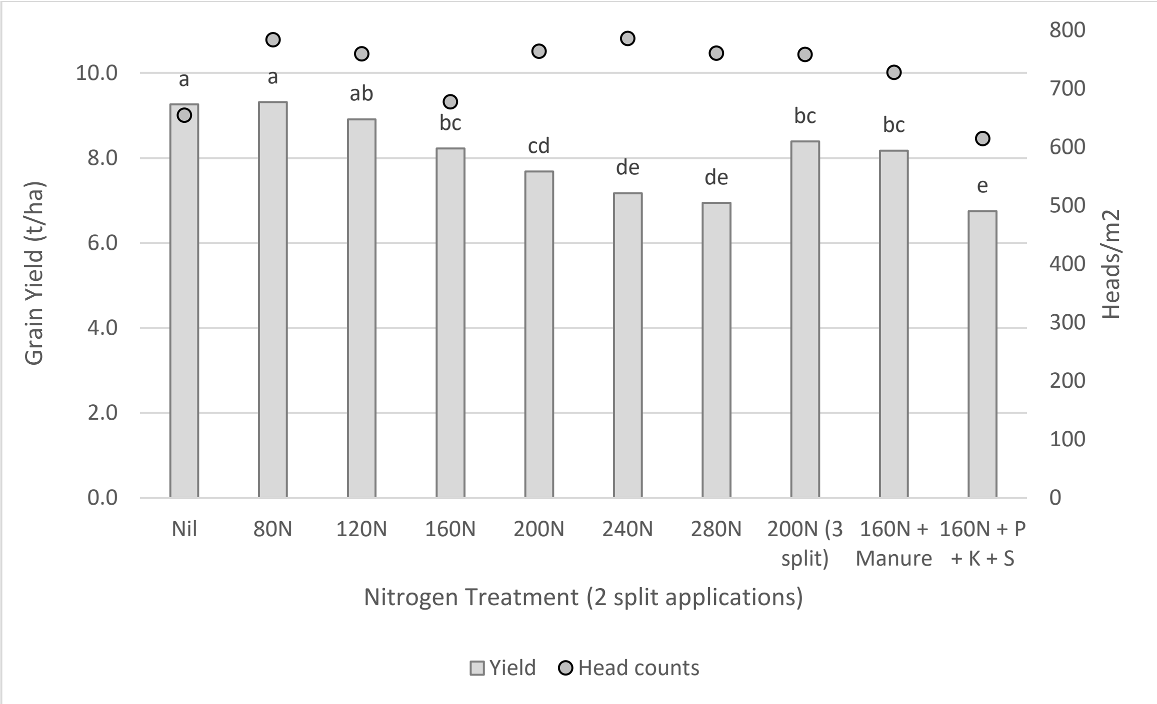

Figure 2. Influence of applied nitrogen, manure and other nutrients on yield and head number – HYC Wallendbeen, NSW 2022. Columns denote grain yield and dots show heads/m^2.

Notes: N applied as urea (46% N) was timed at tillering (21st June) and GS31 (27th August)
Soil available N in winter (4 Jul) - 0-10cm 39kg N, 10-30cm 56kg N, 30-60cm 46kg N
Chicken manure pellets applied at 5t/ha with an analysis of N 3.5%, P 1.8%, K 1.8% and S 0.5%.
Columns with different letters are statistically different P = 0.05, LSD: 0.79t/ha

Table 3. 160 kg/N ha, with additional N, P, K & S was applied as follows to replicate the addition of manure as in the 160N + P + K + S column in Figure 2 above.

Product	kg/ha	**N**	**P**	**K**	**S**	**Date applied**
Mono potassium phosphate	315	0	90	72	0	Sowing
MOP	36	0	0	18	0	21 June
Ammonium sulphate	104	21	0	0	25	21 June
Urea	335	154	0	0	0	21 June
Total		**175**	**90**	**90**	**25**	

The results serve to illustrate that given non-limiting water conditions; fertile soils with high soil N supply have the potential to mineralise enough N to achieve potential yield. This is illustrated by the nil fertiliser rate in Figure 2. In fact, since 2016 in HYC trial work, optimum applied fertiliser N levels have rarely exceeded 200kg N/ha for the highest yielding crops, even though the crop canopies that these yields are dependent on are observed to remove far more N than that (assuming N is baled or burnt at harvest). This indicates N supply in the hyper yielding sites is most likely provided by the mineralisation of N from soil organic matter (SOM) pre-sowing and in-crop. The 8.8 t/ha yield from the nil N treatment for example requires 250kg of soil N/ha at an assumed N efficiency of 70% for humic SOM (Baldock 2019) and a similar efficiency for labile SOM contributions (Peoples et al, 2017). These crop N recovery efficiencies are typically much higher than those achieved with fertiliser N which is often reported at 44% (Vonk et al. 2022; Angus and Grace 2017). Consequently, the same yield (8.8t/ha) supplied entity by N fertiliser would require 400kg N/ha assuming an N efficiency of 44%.

Protecting yield potential

Many regions experienced just how important it is to protect yield potential in 2022. With many growers describing the stripe rust epidemic in 2022 as the worst in 20 if not 50 years. Disease management over the last three years has been shown to be one of if not the most important factors in securing high yielding crops in HYC project trials. It has also been demonstrated to be one of the most important factors in securing higher yields and closing the yield gap in better seasons in L-MRZ regions. FAR Australia in collaboration with Trengove Consulting have been looking at the influence of wheat powdery mildew (WPM) on wheat at Katamatite in a GRDC NGN project. The work whilst not revealing insights into the effect of WPM on yield, did provide an excellent opportunity to examine the influence of stripe rust on the yield of the variety Scepter⦶ in the northern Victorian region. The work illustrated that, whilst it's imperative to have the correct environmental conditions and N inputs to generate yield potential, in 2022, realising yield potential through disease management was even more significant. Figure 3 shows the effect of different two spray fungicide programmes applied to Scepter⦶ in a scenario dominated by stripe rust (and *Septoria tritici* blotch (STB) – data not shown) infection caused by the pathogens *Puccinia striiformis f.sp. tritici.* and *Zymoseptoria tritici*. The first fungicide was applied at third node (GS33) as stripe rust was first infecting the crop canopy. The second application at head emergence (GS57) combined a head and flag leaf spray in what is referred to as a 'straddle spray programme', since the two applications are applied either side of and miss the flag leaf emergence at GS39. The disease pressure was so severe that differences in active ingredient efficacy were not only observed but associated with differences in both disease control and yield response.

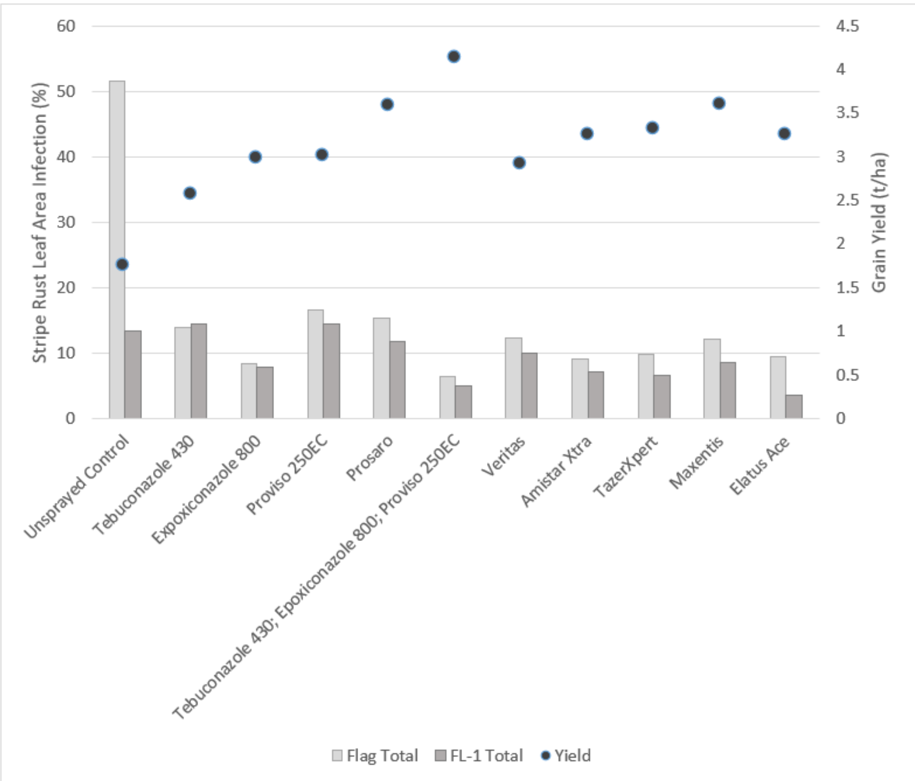

Figure 3. Influence of fungicide product applied in two spray programmes (GS33 & GS57) – FAR Australia Disease Management Centre, Katamatite, VIC 2022 cv Scepter⦶

Columns denote stripe rust leaf area infection, dots denote grain yield, FL-1 denote the leaf one position below the flag leaf.

Notes:

A maximum of 1 application of tebuconazole can be applied per crop. Two applications were used in this trial to demonstrate relative efficacy only.

Use of 2 repeat applications of the same product was used to help distinguish efficacy between products, and whilst 2 applications of a single product per season is on some product labels, there are rate limits and it is not considered best practice for resistance management. Always read and follow product labels.

At Katamatite, two fungicide applications increased yield in Scepter⦶ from 1.75t/ha (untreated) to a maximum of 4.14t/ha. With the second fungicide being applied to established infection, it's important to note that treatments with greater curative activity tended to be more effective. The application of a third fungicide in this research increased yield by a further 0.36t/ha (data not shown). The wider issue the success of fungicide management raises is that pathogen resistance to fungicides is primarily driven by the number of applications of the same mode of action and the scale of industry application. This is why it is imperative for HYC research to incorporate the most resistant, high yielding and adapted germplasm available in order to reduce our dependence on fungicide agrichemicals.

Overall, the HYC project demonstrates that key points can be relevant to lower rainfall regions, particularly in seasons with greater growing season rainfall and higher disease pressure. In such seasons HYC learnings can enable growers and advisers to extract more of the potential in their crops and effectively close the yield gap.

A map of stripe rust pathotypes along with wheat genotype resistance can be found in the further reading section of this paper.

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Further reading

More results from previous HYC research can be found on the FAR website https://faraustralia.com.au/resource

Map of stripe rust pathotypes. https://www.google.com/maps/d/viewer?ll=-35.02928510399337%2C149.8494244663206&z=6&mid=1qzwnH1u0B2apVvpkEKFm0mfBP_7cBknF

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