Agronomic practices for hyper-yielding crop years and environments. Agronomy, varieties, canopy, nutrition, PGR's and foliar disease

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Take home messages

- The hyper yielding crops (HYC) project has successfully demonstrated new yield benchmarks for cereals in the more productive regions of Australia.
- Maximum wheat yields in southern NSW (Wallendbeen) have been achieved with red grained feed wheats and modern fungicide chemistry.
- **Hyper yielding cereal crops require high levels of nutrition**, but not necessarily through increased fertiliser rates. 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.
- At the HYC Wallendbeen site in 2022, fungicide management strategies for stripe rust and Septoria control combined with variety choice was shown to take yield from 1t/ha to 10t/ha.

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 for wheat, barley and canola, both in research experiments and on commercial farms in southern regions of Australia with higher yield potential when compared to traditional grain growing regions. 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 (>450m) in southern NSW (Wallendbeen), in the southern Victoria and SA high rainfall zone (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.

Yield potential

Most crops grown in the Australian grain belt are traditionally yield limited by soil moisture stress. This is more often the case in the low to 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 lack of 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 (period prior to flowering). In 2022, solar radiation was significantly lower than average, whilst temperature during the critical period prior to flowering was generally average. The net effect in 2022 was that even at locations traditionally limited by soil moisture, yield potential was reduced by lack of solar radiation and temperature rather than water limited potential (Table 1).

Table 1. Selected Southern Australian sites and calculated water limited and photothermal quotient (PTQ) yield potentials for 2022. Shaded cells indicate sites where the PTQ was limiting yield potential and not water supply, based on a 25kg/ha/mm transpiration efficiency (adapted from Porker et al., 2023).

Site (nearest town)	Water supply (mm)	Water limited potential yield (t/ha)	Assumed flowering date	Photothermal quotient yield potential(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
Inverleigh (Vic)	564	>12.5	20-Oct	9.9
Yarrawonga (Vic)	582	>12.5	28-Sep	8.5
Millicent (SA)	647	>12.5	30-Oct	9.7
Hagley (TAS)	700	>12.5	10-Nov	11.5
Forbes (NSW)	722	>12.5	30-Sep	8.4
Temora (NSW)	759	>12.5	3-Oct	8.4
Cowra (NSW)	771	>12.5	14-Oct	7.5
Wallendbeen (NSW)	791	>12.5	12-Oct	9.0
Young (NSW)	822	>12.5	13-Oct	8.9
Orange (NSW)	957	>12.5	15-Oct	11.8

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. 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 yield, there is a limit to the extent to which head number can be used to increase yields. In most cases with yields of 10 –15t/ha, 500–600 heads/m^2 should be adequate to fulfil the potential.

So how do we increase grains per m^2 and what is the connection to PTQ.

Whilst more heads/m^2 contributes to yield outcomes, it is typically a higher number 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 the start of flowering (approximately GS33 – 61). This window of growth in cereals covers the period approximately three – four weeks (~300 ˚C days) prior to flowering and is described as the 'critical period'. 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 PTQ 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, yield potential was significantly reduced in 2022 (Figure 1). This is without taking into account 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.

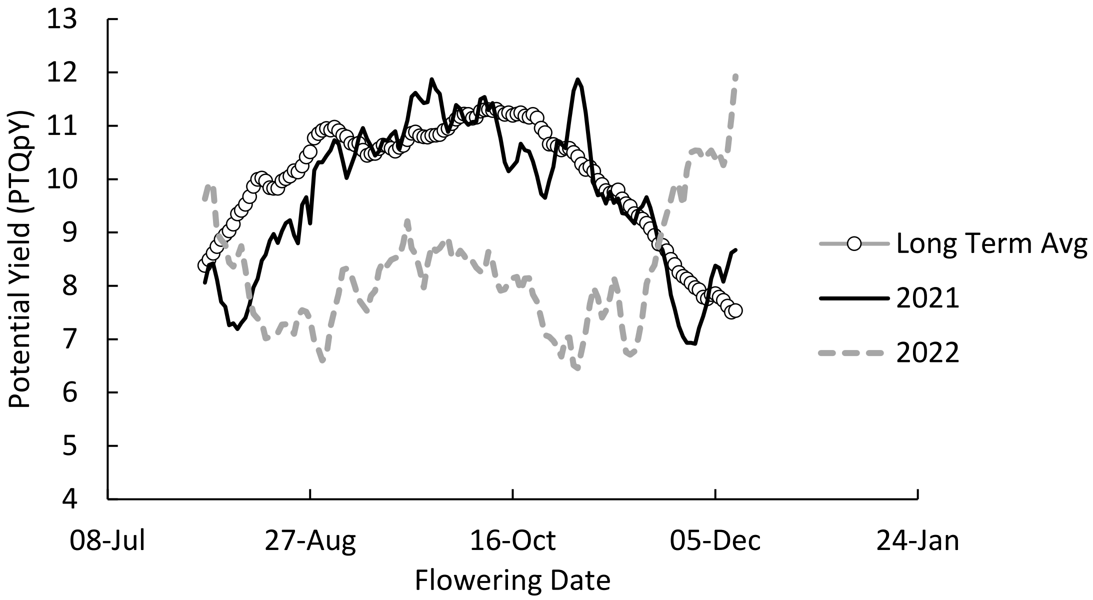

Figure 1. Long term (last 20 years based on Cootamundra BOM data) yield potential based on the photothermal quotient (PTQ) and its relationship with flowering date at Wallendbeen, compared to 2021 and 2022.

Note this is the upper ceiling of yield potential and does not factor in other risk factors such as frost, heat, pests, disease and nutrients, 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.

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 (iv) other factors such as 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 yield (Figure 2). This confirmed a result observed in previous high yielding trials. Despite an application of plant growth regulator (PGR) Moddus® Evo at 0.2L/ha + Errex® 750 at 1.3L/ha at GS31, increasing rates of applied N increased head numbers but also increased lodging during grain fill (data not shown) which led to reduced yield.

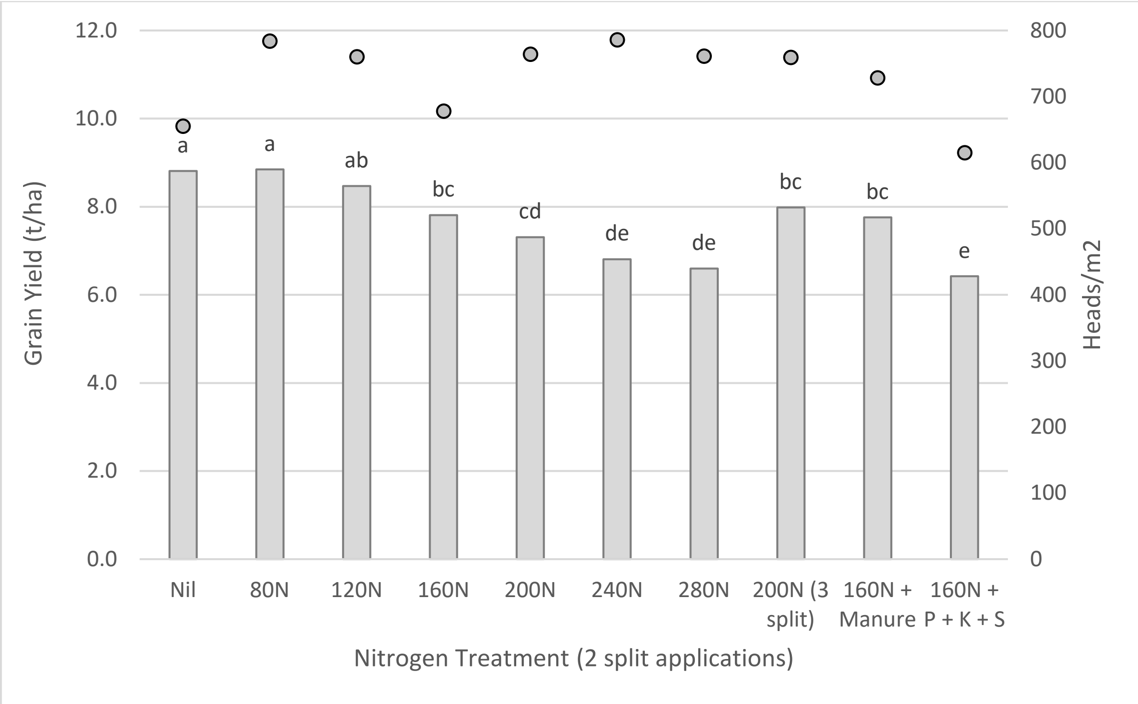

Figure 2. Influence of applied nitrogen, manure and other nutrients on yield and head number – HYC Wallendbeen, NSW 2022. Columns denote grain yield and dots show heads/m^2

Notes: N applied as urea (46% N) was timed at tillering (21st June) and GS31 (27th August)

Soil available N in winter (4 July) - 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 2. Details of the treatment "160N + P + K + S" in Figure 2 above was applied as 160 kg/N ha with additional N, P, K & S to replicate the addition of manure.

Product	kg/ha	**N**	**P**	**K**	**S**	**Date applied**
Mono potassium phosphate	315	0	90	72	0	Sowing
Muriate of potash (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 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. 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 entirely by N fertiliser would require 400kg N/ha assuming an N efficiency of 44%. However, in HYC trial work since 2016, optimum applied fertiliser N levels have rarely exceeded 200kg N/ha for the highest yielding crops, demonstrating that hyper yielding crops can't be grown by just adding more N and that the basis for building high yielding crops is a fertile farming system.

Protecting yield potential

Many regions experienced just how important it is to protect yield potential in 2022. Many growers describing the stripe rust epidemic in 2022 as the worst in 20 if not 50 years. Over the last three years, disease management 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 optimum seasons in low to moderate rainfall regions. In Wallendbeen HYC trials, grain yield was increased from 1t/ha to 10t/ha by combining the best disease management strategy with the best germplasm (variety) (Figure 3). Seven wheat varieties (three milling wheats and four red grained feed wheats) were grown with four levels of fungicide protection. The four levels of fungicide were as follows.

1. Nil – untreated control
2. A single experimental fungicide (FAR F1-19) applied at flag leaf (GS39)
3. A two-spray approach – experimental fungicide (FAR F1-19) at GS33 (3rd node) followed by Opus® 125 at 500mL/ha at head emergence (GS59)
4. A four-unit approach combining at sowing flutriafol on the MAP followed by three foliar sprays – Prosaro® 420 SC at 300mL/ha at GS31, followed by experimental fungicide (FAR F1-19) at GS39, followed by Opus® 125 at 500mL/ha at head emergence (GS59)

Fungicide applications looked to represent a range of integrated approaches to develop profitable and sustainable disease management strategies for high rainfall zone wheat. The four-unit treatment looked to demonstrate a complete but targeted approach of disease management (primarily Septoria tritici blotch (STB) and rusts) by protecting the leaves that contribute most to yield, also known as the 'money leaves'. In this treatment, the flutriafol treated fertiliser offers early protection from stripe rust and STB. In combination with the SDHI/DMI mixture (experimental fungicide (FAR F1-19)) on the flag leaf offering robust protection from STB, and the Prosaro and Opus offering protection against rusts and powdery mildew at stem elongation and head emergence respectively.

The two-spray management (level 3) looks at the idea of a 'straddle approach' where fungicides are applied between the traditional target growth stages. While a compromise on accurately hitting the 'money leaves', this management does provide an option for reducing fungicides if disease pressure, seasonal conditions and other integrated disease management (IDM) strategies allow. The single fungicide treatment centres on the scenario of lower disease pressure where good genetic resistance to disease is present allowing timing 1 (T1) at GS31-32 to be missed. In this case a single application of a robust fungicide on the flag leaf (the most important leaf in contributing to yield) could be the most appropriate.

With the principal diseases being stripe rust and *Septoria tritici* blotch (caused by the pathogens *Puccinia striiformis f.sp. tritici* and *Zymoseptoria tritici*), the levels of infection in 2022 at this site were so severe that not even the four-unit approach to disease management gave full control in the more stripe rust susceptible varieties (rated S and MS-S). None of the varieties had sufficient genetic resistance to be farmed more profitably with no fungicides. In Scepter⦸, the response to the four-unit approach compared to the untreated control was almost 6t/ha whilst with RGT Accroc it was nearly 4t/ha. For the third year in succession, despite low level infection, the varieties Anapurna, RGT Cesario⦸ and BigRed⦸ (KWS Lazuli⦸) showed no significant yield advantage to four units of fungicides compared to one. With RGT Cesario⦸, stripe rust resistance was not complete and an application at GS31 did reduce disease levels. It should be noted that with these high yielding feed wheats, the response to fungicide was still between 1.5 – 3t/ha.

Whilst fungicides can only be considered an insurance (i.e., we don't know what the economic return will be when they are applied), it is clear that when it is wet during the stem elongation period as the principal upper canopy leaves emerge (flag, flag-1, flag-2), fungicide application is essential to protect yield potential. Stripe rust infection was so severe in 2022, that fungicide timing and the strength of the active ingredients being used made profound differences in productivity. Long 'calendar gaps' of over four weeks between fungicide applications (as was the case in own our work) resulted in many crops losing control of the epidemic as unprotected leaves became badly infected in the period between sprays and applications became more dependent on limited curative activity rather than protective activity.

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. This is why it is imperative for HYC research to incorporate the most resistant, high yielding and adapted crop germplasm available in order to reduce dependence on fungicides.

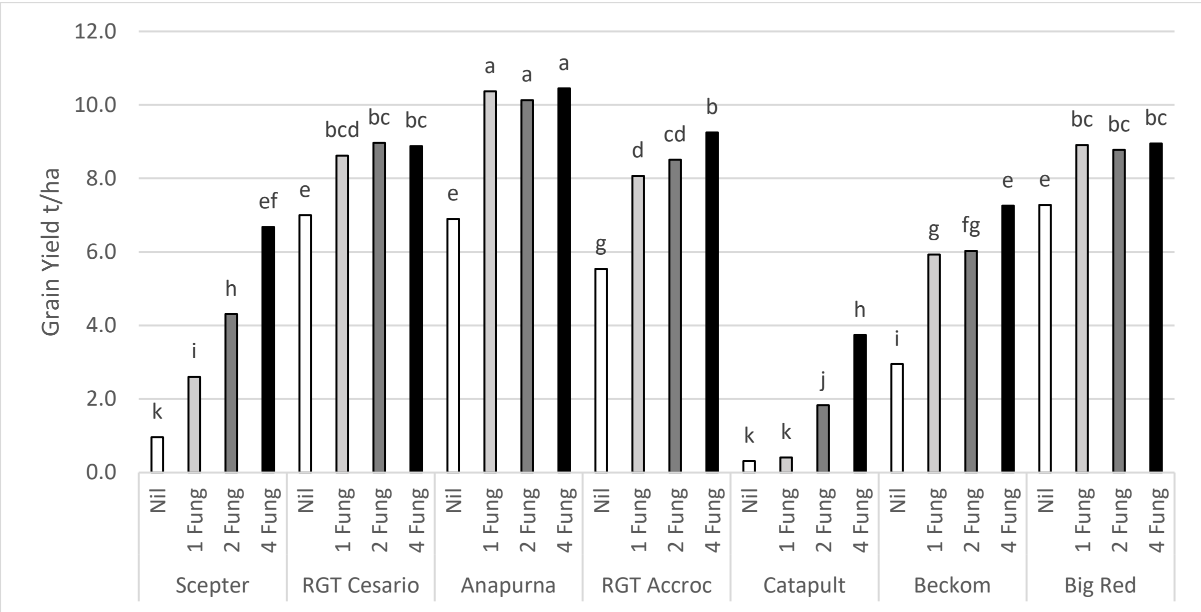

Figure 3. The influence of the number of applied fungicides on wheat varieties at the HYC trial at Wallendbeen, NSW 2022. All varieties presented (except RGT Accroc) are protected by plant breeder's rights.

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

The GRDC hyper yielding crops and National Grower Network (NGN) experiments in 2022 demonstrate how improved yields can be realised in low to medium rainfall zones using management strategies more common in high rainfall zones. The importance of matching soil nitrogen supply to season/yield decile, and disease management inputs in barley to extract increased yield in seasons where soil moisture is not the limiting factor (like in 2022) is highlighted in Table 3.

Table 3. Average effect of in-crop canopy management interventions in barley averaged 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**	
Nil	High		4.3	b	4.1	a	5.0	ef	-		-		-	

Data with different letters are statistically different $P = 0.05$

[1] Nitrogen input

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 420 SC at 300mL/ha) @ GS31
High = 4 x fungicide units. Systiva Seed Treatment, 3 x foliar fungicides including SDHI and DMI chemistry (Prosaro 420SC at 300mL/ha @GS31, Aviator Xpro at 500mL/ha @GS39 and Opus 125 at 500mL/ha @GS59)

[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)

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.

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