CROP SCIENCE SOCIETY
OF SA INCORPORATED

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ABN 68 746 893 290

NEWSLETTER July 2020

The next Crop Science Society Technical Forum is scheduled for Wednesday the 15th July at Roseworthy from 7.30pm.

Welcome to the July issue of the Crop Science Society of SA.

The next Crop Science Society technical forum is Scheduled for Wednesday the 15 July, 7.30pm at Roseworthy. Available seats may be limited due to COVID restrictions & guidelines. This meeting will be the Crop Science Societies Annual General Meeting so members wanting to vote will need to be present.

To view the full AGM agenda click the link below.

The AGM will also feature three short presentations on current research. Members will hear from:

- Kenton Porker (SARDI) on novel approaches to adjusting flowering timing of cereals & managing head loss in barley.
- Jade Rose (PhD student, The University of Adelaide) on nutrient release and nitrogen cycling benefit from pulse crop residues.
- Matt Salomon (PhD student, The University of Adelaide) on effectiveness of arbuscular mycorrhizal inoculants.

If you are unable to attend in person and do wish to be a voting member for the AGM you can participate online via Zoom. The Zoom link for this meeting is https://us02web.zoom.us/j/82604188609.

For those attending our meeting at Roseworthy next Wednesday evening, there will be a chance to meet for an informal dinner at the Roseworthy Hotel beforehand. Please contact Tom Robinson at anashka.farms@gmail.com or on mobile 0400 291 219 to RSVP and for details

Many thanks
Craig Davis
President, Crop Science Society of South Australia

Crop Science Society recognises new life member Dr Hugh Wallwork

Current Crop Science Society President, Craig Davis (left) presenting newly recognized Life Member recipient Dr Hugh Wallwork (right) with his certificate at their

Since 1975 the Crop Science Society of South Australia Incorporated (CSSSA) has advocated for the use of sound science to provide improvements in agricultural crop production for South Australian producers. CSSSA is an active organisation of farmers, farming consultants and agricultural research scientists. It was felt that a society was needed to provide a forum for the exchange of information between people in academic and applied fields; between research, teaching, extension workers, farmers and marketing representatives.

CSSSA provides a forum for the interchange of ideas from a membership extending beyond that spanned by any existing organisation. Currently, the society has over 300 members from rural and metropolitan SA, as well as a small interstate membership. Meetings are held on the third or fourth Wednesday of the month at the University of Adelaide's Roseworthy campus.

At its regular membership meeting, on June 17th, the Society recognised a new worthy recipient of its Life Membership award.

Dr Hugh Wallwork is an influential agriculture researcher. After completing a Bachelor of Science with Honors at the University of East Anglia, a Masters at the Cambridge University and his Post honors Doctorate also at the Cambridge University, studying stripe rust, Hugh has continued on to lead many research & extension projects. Hugh moved to Australia in 1982 to work with the late Dr Tony Rathjen investigating Take-All. In 1984 he succeeded Dr Allan Mayfield in the field of cereal leaf disease research.

With a focus on cereal pathogens he has been instrumental in providing early warnings to the grains industry on disease threats to crops. This has included monitoring of disease populations, assessing diseases for changes in virulence as well as new cereal varieties and breeding lines. Hugh has had a particular focus on the identification and uptake of resistant varieties as the principal method of control.

Hugh has also authored & co-authored many publications including;
"The role of minimum disease resistance standards for the control of cereal diseases." in Australian Journal of Agricultural Research, 58: 588-592 in 2007,
"The use of differential isolates of Rhynchosporium secalis to identify resistance to leaf scald in barley." in Australasian Plant Pathology 40: 490-496 in 2011,
"Use of specific differential isolates of Rhynchosporium commune to detect minor gene resistance to leaf scald in barley seedlings." in Australasian Plant Pathology 43: 197-203 in 2013,

"High yielding lines of wheat carrying Gpc-B1 adapted to Mediterranean-type environments of the south and west of Australia." in Crop and Pasture Science 65: 854- 861 in 2014,
"Re-classification of the causal agent of white grain disorder on wheat as three separate species of Eutiarosporella." In Australasian Plant Pathology. DOI 10.1007/s13313- 015-0367-2 in 2015.

Hugh is a well respected industry member and has been actively involved with the Crop Science Society since 1982. Hugh is well deserved in this recognition & was warmly commended by the members present.

Insights into historical rural development of South Australia – a review by Peter Smith

We all can recall the Stump Jump plough and its impact on cropping in SA and then the rest of the world. R B Smith does not necessarily roll off the tongue as inventor of the plough but his success with innovation and agriculture was short lived and challenging. The following article was published in *Australian Dictionary of Biography*, in 2005 and written by Roger André.

Life Summary- Richard Bowyer Smith (1837–1919)

Birth: September 2, 1837, London

Death: February 4, 1919, Subiaco

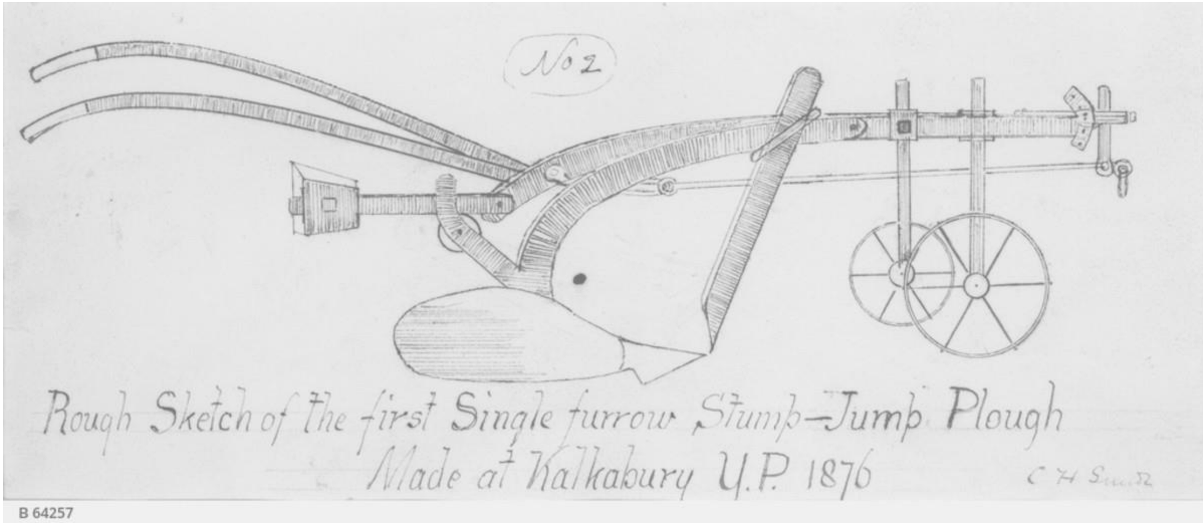
Religious Influence: Anglican

Occupation: Blacksmith, Farm Machinery Manufacture, Inventor, Local Government Councillor

Richard Bowyer Smith (1837-1919), blacksmith and inventor of the stump-jump plough, was born on 2 September 1837 in London, eldest child of Smith Owen Smith, carpenter, and his wife Mary Ann, née Lee. They were to have twelve children, of whom six died in infancy. Accompanying his parents as an infant aboard the *Trusty*, Richard reached South Australia on 15 May 1838.

Owen Smith set up as a builder in Adelaide, but the family lived for a few years in Victoria; Clarence Herbert (1855-1901), the ninth child, was born on 10 August 1855 at Alma. Back in South Australia, Richard was apprenticed to James Gardner Ramsey, an agricultural implement manufacturer at Mount Barker, then went into trade as a blacksmith and carpenter at Port Wakefield. On 23 May 1863 at Kensington, Adelaide, he married with Wesleyan forms Margaret Smith. They had eight children. In 1872 Clarence was apprenticed to Richard as a blacksmith and machinist.

Following an initial trial, Richard, then in business with Clarence at Kalkabury (Arthurton) on Yorke Peninsula, exhibited two prize-winning versions of a stone- and stump-jumping plough at the agricultural show at Moonta in November 1876. The *Farmers' Weekly Messenger* accurately forecast that Smith's invention had the potential to 'cause a complete revolution in tilling uncleared land'. The mechanism allowed the shares to glide over stumps which otherwise required grubbing, a laborious and costly process.



He failed, however, adequately to secure his rights under the Patents Act of 1877 and prosperity eluded him. Late in 1877 he was granted the first licence of the Arthurton Hotel. Although he and Clarence made design improvements to the plough, Richard was struggling to make a living from his trade until (Sir) Robert Dalrymple Ross took up his cause. In February 1882, as president of the Royal Agricultural and Horticultural Society of South Australia, Ross led a delegation to the commissioner of crown lands, recommending that Smith be awarded a grant of land. In the face of rival claims, on 5 September 1882 parliament acknowledged Richard Bowyer Smith as the inventor of the stump jumping plough, rewarding him with a bonus of £500 rather than a land grant. In 1884 he moved with his family to Western Australia, where he exhibited the plough in 1885 but was unable to realize a profitable return on sales.

Clarence had married Emma Sarah Beck in the Congregational manse, Maitland, South Australia, on 26 June 1879. That year he briefly held title to a 228-acre (92.3 ha) section, in the Hundred of Tiparra, on which the stump-jump plough had first been demonstrated. In 1880 he established agricultural machinery works at Ardrossan, attractive for its shipping facilities. He died of renal disease on 25 July 1901 at Ardrossan, having prepared his young sons Alma Owen and (Clarence) Glen to take over the thriving business. When the local community proposed a memorial to Clarence senior, Richard took umbrage, perhaps resentful of his brother's success. He denied that Clarence had played any part in the invention or development of the stump-jump plough, despite the earliest drawings and several subsequent patents bearing Clarence's name. The Ardrossan firm Clarence H. Smith Ltd, incorporated in 1913, did not weather the 1930s Depression. Relocated to Port Adelaide (1935) it went into receivership.

In Western Australia Richard managed a hotel at Beverley, was a member of the Beverley Road Board (1893-95), and operated railway refreshment rooms in 1895-99 before taking up a farming lease at Beverley of 181½ acres (73.5 ha), relinquished in 1911. At a foundry there he resumed making agricultural implements, then established a workshop at Highgate, Perth, in 1912. He was remembered as a dapper man who frequently dressed in a 'frock coat and striped trousers, patent leather boots and spats'. Smith died on 4 February 1919 at Subiaco and was buried in Karakatta cemetery with Anglican rites. His wife, three daughters and four sons survived him.

The Smith brothers' plough was one of the most important Australian inventions of the nineteenth century; by the mid-twentieth century twenty-four-farrow heavy disc ploughs were in use, essentially working on the same principle. The State Library of South Australia holds, among its treasures, Clarence Smith's hand-drawn sketches of the stump-jump plough.

Member in Focus Dr Kenton Porker

I am a Research Scientist with the SARDI Agronomy group based at the Waite Campus and have been involved with the SA Crop Science Society (CSS) since I graduated in 2009. I was first introduced to CSS by Tony Rathjen after a long road trip as an undergraduate. We had just spent the day digging up durum plants in search of Rhizoctonia and crown rot before attending the Roseworthy meeting. After my undergraduate degree I was fortunate enough to get a job in the Waite New Variety Agronomy group where Tony could easily find me and bring boxes of newsletters to fold, or come knocking on the door at 5pm on a Friday afternoon demanding a newsletter article.

The reasons I was motivated to be a part of the CSS then and today, was that it provides a unique forum for debate and to challenge ideas. There really is not many opportunities to do this in other agricultural meetings in SA. I find this experience extremely valuable and I continue to learn more from growers and advisors by being involved.

I think more than ever before we need improved scientific literacy for the challenges that face agriculture, and its forums like crop science that can begin the discussion. I particularly encourage early career researchers in agriculture to engage with the society and continue to contribute technical content that can benefit CSS members and dryland agriculture. The most recent newsletter article I have submitted along with my co-authors outlines some of the major constraints to dryland agriculture and the quest to increase yield. These challenges will be expensive and difficult to overcome but will only be possible if the research community works together with growers and advisers in appropriate farming systems context.

One of the really fun projects that I am beginning to work on in 2020 is the GRDC "Hyper-yielding crops" led by FAR Australia. Below is a picture (figure 1) from Millicent in 2018 where we grew enough biomass to sustain a 14t/ha grain yield, however only (I know right!!) achieved ~8 t/ha due to a low

harvest index primarily from lodging. Having grown up in the Mallee I am used to low yields and get excited every time the season requires extra N or a fungicide. This will be a fun challenge to try and routinely achieve 10t/ha in the high yielding environments.

One of my favourite trials that I have been involved was located at Feldkirchen in upper Bavaria, Germany (figure 2.). This trial was part of my PhD hosted by Secobra, where Compass (Right) and

Commander (Left) barley flowered in about 40days due to long days and warm temperatures. Yields were ~5t/ha but it was here where I was somewhat comforted to learn that cold induced sterility was not just an issue unique to Australian conditions.

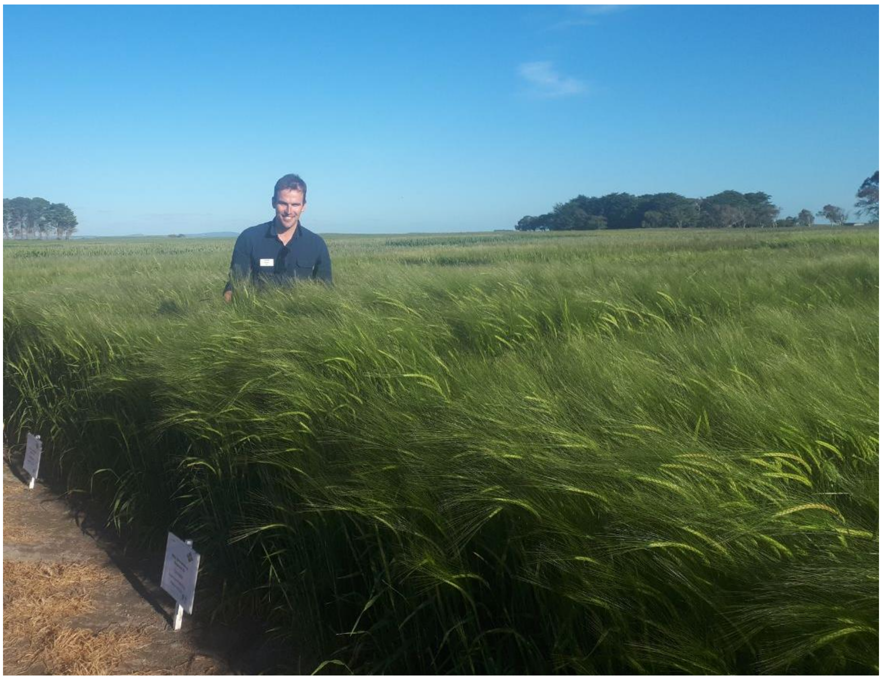


Figure 1. High yielding barley crops at FAR Millicent site in 2018 as part of a SAGIT trial benchmarking yields in the high rainfall zone, the dry matter pictured here was greater than 25t/ha

Figure 2. Compass (Right) and Commander (Left) barley at Feldkirchen in upper Bavaria, Germany flowered in about 40days due to long days and warm temperatures. Kenton Porker (SARDI) demonstrates novel research into modifying head emergence timing in cereals.

Discussion paper - Busting the big yield constraints – where to next

James Hunt*[1]*, John Kirkegaard*[2]*, Corinne Celestina*[1]*, Kenton Porker*[3]*.

[1]La Trobe University; [2]CSIRO Agriculture & Food; [3]SARDI.

This paper can also be found online at https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2020/02/busting-the-big-yield-constraints-where-to-next and was part of discussion paper for the GRDC Advisor Updates at Bendigo 2020

Take home message

- Recent yield increases associated with improved genetics and agronomy (25kg/ha/year) are struggling to counteract the yield decline due to climate change (-24 kg/ha/year), and in coming decades it is likely that yield gains need to double to maintain profits.

Why increase yield?

Cost of production ($/t) is an important factor influencing the ability of Australian grain growers to compete in export markets. One of the main ways in which Australian grain growers have been able to maintain relatively low costs of production despite declining terms of trade has been by increasing crop yield with relatively small additional overhead and input costs. While ways of reducing overhead, input and transport costs can be found (for example; through economies of scale), yield increases are still an important way in which cost of production will be kept at an internationally competitive value in the future. Yield increases are also necessary to meet the goals of sustainable intensification, whereby the additional food required for a growing global population is produced on the same area of land that is currently farmed, without the further destruction of natural ecosystems. This paper will take a brief look at where historic yield increases in Australian crop (particularly wheat) production have come from, and where we believe future gains can be made. It is based on a chapter written for the book 'Australian Agriculture in 2020', recently published by the Australian Society of Agronomy (Hunt et al. 2019a), details of which can be found in the useful resources section within this paper.

Yield, yield and yield

The concept of potential yield (PY), Figure 1, and yield gaps is crucial when looking at ways to improve yield and we follow the nomenclature of Fischer (2015). The most important definition for dryland crop production in Australia is water limited potential yield (PY_w), defined as the yield of the best cultivar under optimum management with no manageable constraints (for example; nutrient deficiency, weeds, disease) except for water supply (Figure 1). Farm yield (FY) is yield achieved by growers in their fields. The difference between FY and PY_w is termed the yield gap. Economic yield (EY) is the yield attained by growers when economically optimal practices and levels of inputs have been adopted while facing all the vagaries of weather (Figure 1). Economic or attainable yield is typically 75-85 % of PY_w (van Ittersum et al. 2013). The difference between EY and FY is the exploitable yield gap. Hochman et al. (2017) describes the proportion that FY comprises of PY_w as relative yield.

The yield gap of an individual farmer is dependent on management skill and level of investment in inputs, but also incentives and capacity to achieve higher yields. Management skill means the ability of a farmer to use management and inputs to reduce the biotic (weeds, pests and diseases) and abiotic stresses (water, nutrient and temperature stress) placed on crops. The different points in Figure 1 describe different situations under which growers may or may not be achieving potential yield. The first point describes a farmer with a high level of management skill, but who under-invests in inputs and is therefore not achieving economic yield. The second point describes a farmer with a high level of skill and appropriate investment in inputs who is achieving economic yield. This farmer has closed the exploitable yield gap.

The third point describes a farmer with a high level of skill who is over investing in inputs and while exceeding economic yield, is not as profitable (due to higher costs of production) or is more exposed to risk than the second farmer. The fourth point describes a farmer who is investing enough inputs to achieve economic yield, but due to a lack of management skill has an exploitable yield gap. This farmer will obviously not be as profitable as the second farmer. To close yield gaps, the first farmer needs to invest more inputs while maintaining current level of management skill. The fourth farmer needs to improve their management while maintaining current levels of inputs. The third farmer has closed the yield gap but can afford to invest less in inputs while maintaining their management skill, thereby increasing profits.

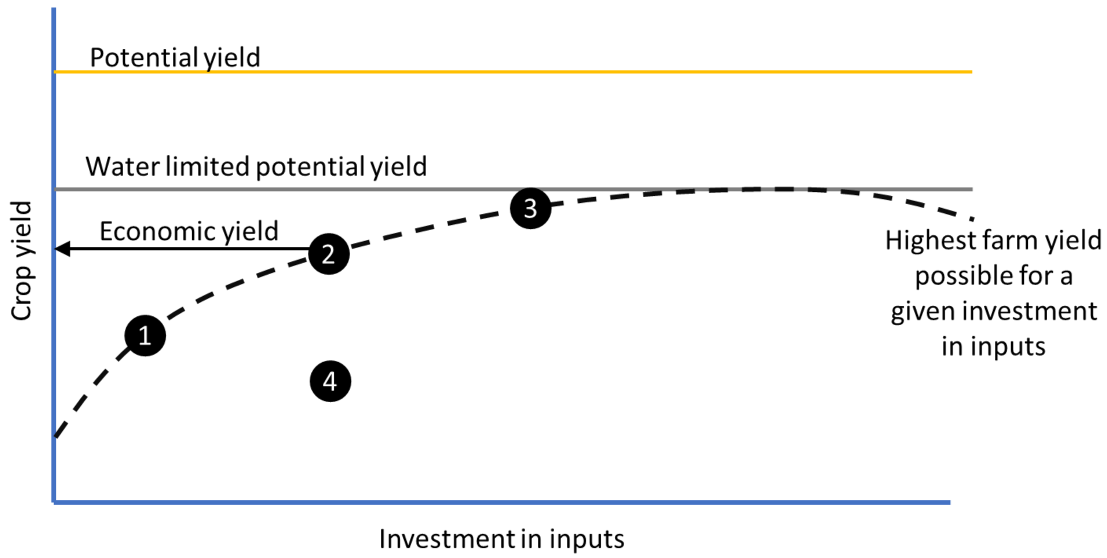


Figure 3. A graphical representation of potential yield, water limited potential yield, economic yield and farm yield. The numbered dots represent growers with different yield gaps and different reasons for those yield gaps.

Where do yield increases come from?

Yield of crops is determined by the interaction between genotype (G = species, cultivar), environment (E = soil and climate) and management (M = rotational position, fallow management, tillage system, sowing date, fertiliser, control of weeds, pests and disease etc.) which is referred to as G x E x M. The case of wheat (and likely other grain crops) in Australia makes an interesting case study, because the climate has deteriorated (rainfall decreased and temperature increased) and reduced water limited potential yield by 27% during the period 1990 to 2015 (Hochman et al. 2017), which is equivalent to 24kg/ha/year (Ababaei and Chenu 2020). However, growers have maintained yields by adopting improved genotypes and management practices and increased farm yield relative to water limited potential yield (closed the yield gap) at a rate of 25kg/ha/year (Hochman et al. 2017). In other words, climate change has effectively robbed the industry of the yield gains it needs to stay competitive.

Of course, national averages can be deceptive; many leading growers have increased yields despite climate change by increasing water-use efficiency, and therefore, remain globally competitive. For others, there is some room to move in terms of yield gap closure. Australian wheat growers are currently achieving 55% of water limited potential yield (Hochman et al. 2017), meaning that for many growers there still exists a substantial yield gap, and yield could be further increased through adoption of best practice. Leading growers have closed the exploitable yield gap, and increased yield requires an increase in water limited potential yield (van Rees et al. 2014).

Past yield increases

Throughout history, increases in crop water productivity have rarely been attributable to an individual innovation in technology or farming practice. Increases have occurred when new and old technologies and practices combine to form improved systems that overcome a constraint to production (Kirkegaard 2019). In the example of Australian wheat production, the yield gap closure of the last 30 years has been due to many disparate technologies combining to form improved systems. The advent of non-selective knockdown herbicides (mainly glyphosate) and grass selectives drove the rapid adoption of no-till (Llewellyn et al. 2012) which improved soil water conservation and allowed earlier sowing (Stephens and Lyons 1998; Flohr et al. 2018c). Wheat was increasingly grown in rotation with broadleaf break crops (canola and pulses) rather than other cereals or weedy pastures which enhanced disease and weed management, and in the case of cereals following pulses, reduced fertiliser N requirements. Summer fallow weed control further increased soil water conservation, N accumulation and reduced root disease burdens (Hunt et al. 2013). Meanwhile breeders consistently achieved genetic yield progress of 0.5% per annum (Siddique et al. 1990; Sadras and Lawson 2011; Fischer et al. 2014; Kitonyo et al. 2017; Flohr et al. 2018b) and overcame significant biotic and abiotic constraints to production which interact with management (cereal cyst nematode, stripe rust, acidity, salinity, boron). Early sown, disease free crops responded profitably to increasing N fertiliser, applications of which tripled over the last 30 years (Angus and Grace 2017).

Future yield increases

Yield increases comparable to or exceeding those of the last 30 years are necessary to keep Australian growers competitive and to meet the goals of sustainable intensification. Fischer and Connor (2018) estimate that crop yields must increase at around 1.1% per year globally to ensure adequate food supply. While Australian growers have been able to close the yield gap by 25kg/ha/year (equivalent to 1.2% per year increase in relative yield, Hochman et al. 2017), declining rainfall and increasing temperatures have reduced water limited potential yield at a rate of 24kg/ha/year.

Significant yield gains in the coming decades requires a transformational change in the way we do research, development and extension. We argue that focussing research effort on developing synergistic systems that overcome current and future production constraints, combined with effective extension and adoption, will accelerate increases in yield. This will require a coordinated effort from multi-disciplinary teams, and in Hunt et al. (2019a), we describe a process of 'transformational agronomy' to achieve this. Briefly, agronomic researchers must work closely with growers and advisers to accurately define and quantify constraints to production. Solutions can then be sought and evaluated from diverse sources. Multidisciplinary teams with leadership from agronomists and close cooperation with growers and advisers will be required to achieve this.

Once solutions have been evaluated and tested using a combination of crop simulation, small plot experiments and paddock-scale experiments in growers' fields, research teams need to work closely with growers and advisers to build and integrate improved, robust and adoptable farming systems that overcome the intended constraint.

Three constraints follow that we believe could be overcome with the multi-disciplinary research approach that is embodied in transformational agronomy. Indeed, if these could be achieved, we believe it would lead to transformational changes in production and profit for Australian growers. These are complex problems and will not be overcome cheaply or easily, but the pay-off from doing so would justify the investment.

Removal of N limitation

Nitrogen deficiency remains the single biggest factor contributing to the sizeable exploitable yield gap in Australian wheat production (Hochman and Horan 2018) and likely other non-legume crops (barley, oats, canola) as well. Even leading growers struggle with N management in favourable seasons (van Rees et al. 2014). At first this appears somewhat paradoxical; N management in grain crops should be extremely simple – crop requirement is well related to yield as described by the simple rule of thumb taught to all budding agronomists: 40kg/ha N per tonne of anticipated wheat yield. The supplies of N to the crop are also readily quantified – mineral N in the soil prior to sowing can be cheaply and easily measured from intact soil cores. Mineralisation is more difficult to estimate but it is possible, and is self-correcting in that spring rain which leads to higher yield potential, also promotes more N mineralisation. The complexity comes in reliably estimating anticipated yields. This requires no less capability than the accurate prediction of weather several months in advance. But the difficulty arises from Australia's extremely variable rainfall. For instance, in southern NSW when growers need to make decisions regarding post-emergent N applications (typically in July-August), possible yields range from 0t/ha to 7t/ha in seasons with no stored soil water prior to sowing, and yield and N demand all depend on September and October rainfall. In addition, over-fertilisation with N can reduce both yield and grain quality through haying-off (van Herwaarden et al*.* 1998). N fertiliser is also a costly input and, mindful of environmental losses (Turner et al. 2012; Schwenke et al. 2014), many growers tend to err on the conservative side in their applications.

There have been consistent attempts to improve prediction of yields and to make N management more precise. This has included the use of forecast systems (Asseng et al. 2012) and decision support systems that integrate soil resources and management variables, and present likely response to N inputs in probabilistic terms (Hochman et al. 2009). While seasonal forecasts are likely to improve, they will never be perfect. Given the substantial nature of the problem, a fresh approach is required.

One such solution that may work in environments with low N losses (for example; low rainfall areas with high soil water holding capacity) is the use of N fertiliser to maintain a base level of soil fertility ('N bank') sufficient to achieve water limited potential yields in the majority of growing seasons (as is currently done for phosphorus).

Implementation of this strategy would need to consider the amount of mineral N in the soil profile and to adjust inputs for carry-over of previously applied N fertiliser not used by the crop. If applied appropriately at the time of rapid crop uptake, environmental losses from the 'N bank' would be low in farming systems where stubble is retained and the majority of applied N is either taken up by the crop or immobilised into organic forms. Losses could be further reduced through use of higher efficiency N application strategies (e.g. deep and mid-row banding).

Once the N banks are built, the cost of N fertiliser for growers is deferred into the season following rather with the season of high yields; this could have substantial economic value through improved cash flow and tax benefits. It may also reverse the mining of soil N that has occurred under Australian crop production since the decline in area of legume-based pastures (Angus and Grace 2017).

A multidisciplinary team is essential to test this potential solution. It requires accurate measurement of N losses and N cycling within the soil, and this requires discipline-specific expertise from within the field of soil science. In addition, economic assessment will be critical, and an investigation of management techniques to minimise possible negative effects on yield and quality from high levels of soil mineral N is required. Pre- and post-experimental crop simulation would be essential to test assumptions, identify locations and treatments that would be promising to test in the field, and extend field results over multiple sites and seasons. If found to be successful, geographic information system tools (e.g. yield and protein mapping) would allow even greater efficiencies through mapping of N removal in grain.

The 'N bank' concept has been tested using simulations at different rainfall locations in southern NSW, and were found to increase yields with minimal environmental impact (Smith et al. 2019). The first field experiment designed to test this was funded by La Trobe University and established by BCG at Curyo in 2018. The first two years of results indicate that 'N bank' strategies are equally profitable as attempting to match N inputs to seasonal yield potential using Yield Prophet® (

Figure 4). More research is required to evaluate the approach across environments and to closely measure N losses.

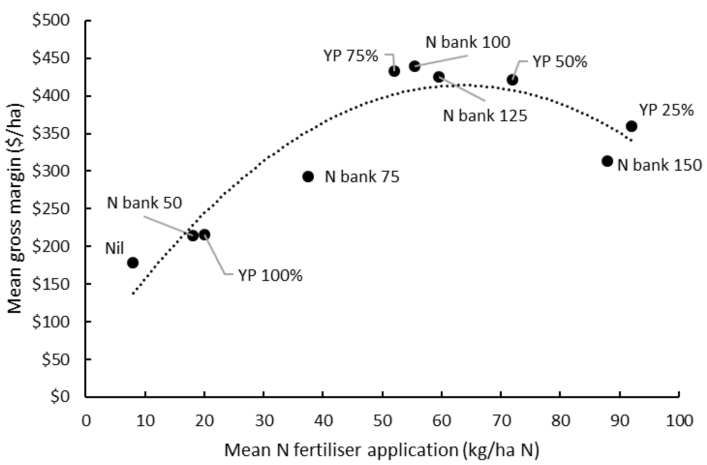


Figure 4. Mean annual N fertiliser application and mean annual gross margin 2018-2019 for different N management systems (N bank vs. Yield Prophet®) being tested in an experiment at Curyo in north west Victoria. The number following the Yield Prophet® (YP) treatments is the probability of different yield outcomes occurring at time of top-dressing in July (e.g. YP 75% targets each year the yield at which there is a 75% chance of exceeding). The numbers in the N banks treatments represent the total N supply (soil mineral N + fertiliser) that each treatment is topped-up to with N fertiliser (e.g. in the N bank 125 treatment, if 75kg/ha of soil mineral N is measured prior to sowing, it is topped up to 125kg/ha total N supply with 50kg/ha fertiliser N).

Crop establishment in the absence of autumn rainfall

From the early breeding work of Farrer, much of the agricultural research conducted in Australia has aimed to coincide critical periods of yield determination in crops with climatically optimal conditions for growth. The cool, wet winters during which crops are grown in Southern and Western Australia often transition rapidly into hot, dry conditions with supra-optimal temperatures and limited soil water. When combined with spring frosts, this creates a reasonably narrow period during which crops must undergo their critical development phases (e.g. flowering) for yields to be maximised (Dreccer et al. 2018). While the concept of the optimum flowering window has long been known (Anderson et al. 1996), it has been the advent of computer simulation that has allowed them to be quantified for multiple locations across many seasons, for wheat (Flohr et al. 2017) and canola (Lilley et al. 2019) and barley (Liu et al. 2020). Shifting crop development closer toward optimal flowering periods has been the major mechanism behind many of the transformational changes in Australian crop production. This includes iconic advances such as the release of Federation wheat with its faster development pattern (Pugsley 1983), the rise of no-till which allowed much earlier sowing (Stephens and Lyons 1998), and more recent shifts to dry and early sowing (Fletcher et al. 2016; Hunt et al. 2019b).

Recent quantification of optimal flowering periods has revealed that leading growers are now coinciding critical periods with seasonal optima (Flohr et al. 2018c). The only times they do not achieve timely flowering is when they have been unable to do so due following dry autumns with insufficient soil moisture to allow seeds to germinate and emerge. Somewhat ironically, this new understanding of optimal sowing times has coincided with declining autumn rainfall (Pook et al. 2009; Cai et al. 2012) making it harder than ever for growers to achieve optimal flowering periods. This defines our second opportunity to overcome a major constraint to crop production – achieving crop establishment in the absence of favourable autumn rain. Once again, an integrated solution to this constraint demands multidisciplinary expertise led by a generalist with appreciation of the G x E x M context. Input is required from disciplines of agricultural engineering, plant physiology, genetics and soil physics.

Knowledge of the regulation of seed germination has developed greatly in recent times, yet our understanding of the mechanisms causing variation of plant establishment in the field remains limited. This is probably because most seed biology experiments are performed in laboratories under optimal conditions, whereas seeds in the field are subject to a complicated soil matrix where they experience a variety of different stresses (Finch-Savage and Bassel 2015). Domestication and breeding have provided incremental improvements in the ability of crops to germinate and emerge under sub-optimal conditions, but here we discuss ways in which agronomically directed research could be applied to transform seed performance when surface soil is dry.

Soil water potential is a major factor in determining seed germination and plant establishment. Many species can germinate at soil water potentials well below those that maximise plant growth (Wuest and Lutcher 2013). Distinguishing between adequate and marginal water to enable germination can be difficult for growers – there are no well-defined criteria for determining if a soil contains a high enough water content to germinate different crop species. At water potentials above -1.1MPa, germination rates are rapid (Wuest and Lutcher 2013). Water potentials below this slow the speed of germination, and below -1.6MPa, germination ceases. Pawloski and Shaykewich (1972) showed that these effects were similar between soils, even when soils differ in hydraulic conductivity.

Crop establishment could be enhanced by the ability of seeds to germinate at lower water potentials. This could be achieved by genetic or other means. Singh et al. (2013) found differences between wheat cultivars in the ability to germinate at low water potentials. Genetic variation for rates of seed water uptake (which initiates germination and is the first stage in the malting process) exists in barley, and it has been suggested that this could be exploited by breeders for the benefit of the malting and brewing industries *(*Cu *et al.* 2016). The same principles and expertise could be applied to field germination at low water potential. An obvious trade-off that may arise with the genetic ability to germinate at low water potentials is susceptibility to pre-harvest sprouting (Rodríguez et al. 2015). Expertise from plant physiologists concerned with the regulation of dormancy would be essential to harness this opportunity.

Beyond genetic means, strategies for manipulating germination processes used in horticulture crops and rice could be evaluated. Seed priming techniques limit the availability of water to the seed so that imbibition and seed metabolism commences, but germination is not completed (Halmer 2004). Seed priming has potential to reduce the lag time between imbibition and emergence, and to synchronise seedling emergence. It can improve emergence of wheat under low temperatures (Farooq et al. 2008), but not necessarily under low water potentials (Giri and Schillinger 2003). The inclusion of plant growth regulators, hormones or micronutrients during priming can also improve germination and emergence (Jisha et al. 2013; Ali et al. 2018). It is clear from the literature there are many potential solutions that could improve seed germination and establishment at low water potentials. Extensive field appraisal of these techniques is required.

Inadequate moisture at the ideal sowing depth has led to growers sowing deeper to seek moist soil and to make use of residual moisture stored from summer rains or the previous growing season. Their ability to do this is currently restricted by the availability of sowing equipment capable of placing seeds into moist soil at depth, and the ability of plants to emerge from depth. Coleoptile length is an important trait determining the success of emergence from depth, but there are also other genetic factors involved (Mohan et al. 2013). Modern Australian semi-dwarf wheat and barley cultivars show poor emergence when sown deep (greater than 8cm) due to short coleoptiles (Rebetzke et al. 2007). Warmer soils in the future may further exacerbate poor establishment and especially with deep sowing.

Pre-experimental modelling indicates substantial benefits for crop yield in southern Australia if machinery and genotypes could be developed that allowed placement and emergence of seed at depth (Kirkegaard and Hunt 2010; Flohr et al. 2018a). Establishment of crops in this way is routine in the drylands of the Pacific North West USA, where annual rainfall in some regions is as low as 160mm. Seeds of winter wheat and other crops are sown deep using deep furrow drills into moisture remaining from 13-month fallow periods and can emerge with 10cm to 15cm of soil covering them (Schillinger and Papendick 2008). Rebetzke et al. (2016) have argued the case for Australian breeders to use novel dwarfing genes that do not suppress coleoptile length. Larger seed size is also known to improve deep-sown crop establishment. Large-seeded canola improved the timeliness of establishment and subsequent grain yield when rainfall for crop establishment was marginal but there was moisture available deeper in the seedbed (Brill et al. 2016).

Frost, drought and heat

While optimisation of flowering times allows the combined stresses of drought, frost and heat to be minimised, these abiotic stresses still take a large toll on crops every year, and will continue to do so even if establishment in the absence of autumn rain could be achieved (see preceding discussion within this paper). Most avenues minimising the risks of frost, drought and heat have been explored, the only remaining means to increase yields in the face of these cardinal abiotic stresses is through crop tolerance. It is our opinion that this will most likely be achieved via genetic solutions, but these must be considered in an appropriate G x E x M context.

Frost, drought and heat risks are inextricably linked. Frost risk declines as flowering is delayed later into the spring, while the risk of drought and heat increases. This means that tolerances to all three stresses are not necessary to improve yields, and if tolerance can be found to either frost on the one hand, or drought and heat on the other, then the optimal flowering period will shift accordingly to reduce the likelihood of occurrence of the opposing stress. That is, if we can minimise frost stress then we can reduce the effects of drought and heat stress by flowering earlier, and vice versa. The value of this approach has been demonstrated by economic analyses of potential frost tolerance, where the benefit of shifting flowering time earlier to avoid drought and heat has also been quantified (An-Vo et al. 2018). Therefore, the important question is which of these stresses will be cheapest and easiest to solve?

Drought and heat are perhaps easier targets compared with frost in that they are reasonably easy to screen for within a breeding program, and some genetic regions associated with combined drought and heat tolerance have been identified (Tricker et al. 2018). Conversely, frost is virtually impossible to recreate under controlled conditions and tolerance is extremely difficult to identify. Heat and drought often interact. Heat tolerance in the absence of drought is associated with stomatal opening and rapid water-use that depresses canopy temperatures relative to the atmosphere (Reynolds et al. 1994). For heat tolerance to be useful in the Australian context, it must be effective under limited water supply (Hunt et al. 2018; Tricker et al. 2018).

While there may be some promise in selecting morphological traits known to confer both heat and drought tolerance, the greatest and most cost-effective progress may be made by breeders selecting for high yield at late flowering times where crops would be routinely exposed to concurrent drought and heat stress. However, this is where the wider crop physiology and management context becomes important. It would be crucial that late flowering be achieved with slow developing cultivars sown early and thus exploit a full growing season rather than by late sowing of faster developing cultivars where yield potential would be limited by shallow rooting depth and low biomass accumulation (Kirkegaard et al. 2015; Lilley and Kirkegaard 2016).

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Figure 4 is funded by La Trobe University Research Focus Area 'Securing Food, Water and the Environment' and conducted in collaboration with BCG and CSIRO.

Submission to the Research and Development Enquiry.

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Since 1975 the Crop Science Society of South Australia Incorporated (CSSSA) has advocated for the use of sound science to provide improvements in agricultural crop production for South Australian producers. CSSSA is an active organisation of farmers, farming consultants and agricultural research scientists. It was felt that a society was needed to provide a forum for the exchange of information between people in academic and applied fields; between research, teaching, extension workers, farmers and marketing representatives.

CSSSA provides a forum for the interchange of ideas from a membership extending beyond that spanned by any existing organisation. Currently, the society has over 300 members from rural and metropolitan SA, as well as a small interstate membership. Meetings are held on the third or fourth Wednesday of the month at the University of Adelaide’s Roseworthy campus.

In recent years due to past government policy, Agricultural research and development (R & D) has been on a declining trend and has reduced the progress of Agricultural science in this state. The flow on effect has hindered the progress of the broader agricultural community as at the same time we have seen significant interstate developments. The reduction in research positions held at key institutions such as the Waite & Roseworthy Campuses of the Adelaide University has been apparent, and it is critical to reverse this trend, and the larger trend in regional decline. Whilst the private sector employment & investment has increased marginally, this has not accounted for the reductions in the government and tertiary education sectors.

The growth of scientific and cultural knowledge and understanding of environmental and agricultural systems has been an instrumental source of value for the state. The leadership from many sectors of the Ag research industry has led to national & international recognition, including life members of the Crop Science Society. This leadership has imparted significant knowledge on the bulk of the membership which has led to innumerable gains for the industry as a whole.

The extension of key R & D has led to improved gross production as well as an increased efficiency in highly competitive markets and changing environments. There are many vectors for extension of R & D nationally. At the state level, tertiary institutions, government departments, public bodies (such as CSSSA) and private sectors are all critical in dissemination of this. Investment in R & D is also critical to extension.

The retention of regional industry and labour for rural economies has been an ongoing difficulty for the state. It is well documented from the initial expansion of agriculture in the late 1800's. The shift of focus of agricultural research from government farms to the tertiary education sector and private industry has not been sufficient to maintain the rural focus. The decline in "Government Farms" has been partly offset by investment in urban research capacity but the cooperative funding has not been sufficient to maintain the rural focus. Skerrick's of this past investment can be seen at the Roseworthy Farm, Minnipa Ag Centre, Turretfield Research Station and Clare PIRSA/SARDI to name four. An increase in investment to specifically facilitate regional research and education is critical to maintain the local research capacity to maximize local growth opportunities. There is also a need to consider making regional positions permanent, rather than as two or three year contracts or funding cycles, to provide security to the work force.

The existing labour force is limited in its capacity at the regional level to facilitate research & extension opportunities within the industry. There is an opportunity to increase current work placement programs and develop scholarship opportunities which could form part of tertiary undergraduate and postgraduate study. Basing these at the regional level will increase the local capacity significantly.

South Australian businesses’, universities’, and research institutes’ R&D funding can be increased by aligning financial rewards from funding bodies to goals that are set to increase value adding and manufacturing. Tax offsets can also be tailored to promote investment by business in higher risk, higher reward opportunities, which may presently be ignored in favor of lower risk research business models.

Further on education, it is exceptionally important that young researchers develop local knowledge with their study and in extension of their research. Having locally trained researchers & education providers will ensure enduring benefits for the industry. The reduction of government funded R & D has reduced the number of employment opportunities for graduates and hence reduced enrolments. It is fundamentally important to re-instate this capacity through scholarships, bursary's, co-funded positions (with industry) & direct funding of key positions.

Recently, there has been an up-tick in the interest in Ag Science at secondary & tertiary education levels. This shows that the improvements in awareness & education is providing required gains. This must be maintained, or even increased if the industry is to maintain a steady stream of quality graduates.

We invite the Commission to make contact with the society if required for further details with regards to the enquiry.

Yours sincerely,

Craig Davis.
President of the Crop Science Society of SA (Inc.)