CROP SCIENCE SOCIETY
OF SA INCORPORATED
C/- Waite Campus
PMB No 1, Glen Osmond, South Australia 5064
ABN 68 746 893 290

NEWSLETTER

Crop Science Society Newsletter

No 328 OCTOBER 2019

YITPI FOUNDATION FORUM
"on country"

Willangga Yerta / the Willunga Basin
a Bicultural Landscape

2 – 3.30 pm Saturday 19th October
Kanyanyapilla* near McLaren Vale

Speakers

Karl Winda Telfer, senior custodian, Mullawirra
parngkarra Keryn Walshe, archaeologist
Gavin Malone, cultural geographer

Followed by discussion & light refreshments

Attendance at this event is free but please register to secure a place.
RSVP and further enquiries to convenor, Maarten Ryder
maarten.ryder@adelaide.edu.au Tel 0409 696 360

This forum is generously supported by a grant from the Yitpi Foundation

**** Kanyanyapilla location: SW corner of Pethick Road and Branson Road, McLaren Vale NOTE: the event will be held outdoors (seated), or under cover in case of bad weather.***

Peter Smith

Secretary

I joined the Crop Science Society in the 1980's thanks to an invitation by my good friend Tony Rathjen. Tony and I would travel together to meetings and in the early days he would fill in the gaps as I questioned him on our return journey to Adelaide. Tony taught us very clearly at Uni. how to analyse a scientific article and was brutal if our endeavour did not meet expectations. In the 80's we got together again when I arrived at Urrbrae and began teaching Crop Production. My students gained enormously from our visits to the Waite Barn to learn about wheat breeding, agronomy and flour characteristics and the generosity from Tony provided, opened windows to scientific investigation and careers for them.

Teaching crop production and agronomy evolved to be the most enjoyable and the high light of my teaching and the Crop Science Meetings and Field Trips were central to updating my knowledge from both the speakers and the fantastic discussion which resulted at the events. In addition I met leading scientists and farmers who contributed significantly to student learning through visits to farms and laboratories.

Much of my undergraduate training focused on animal production and biochemistry although I had a lot of experience with cropping in the Mallee. So as a "born again" agronomy student and teacher (at the same time) I had a strong passion for stubble retention and 'no till' farming. I have very strong memories in the early 90's when teaching year 12's that I was fighting the tide of student opinion on this philosophy, as they would take the ideas home on the weekends and come back with renewed vigour in their opinions after consulting with dad. However the conversations in class were fantastic and led to some to the best teaching experiences for me. By the end of the 90's opinions were far more balanced and by 2014 when I retired from teaching all students from farms were practicing no till or some close variant. In addition a number of my students changed their career direction and chose to study agronomy and have taken up employment in the industry.

During this time I was invited to join the Crop Sc. committee and later to join the Grains and Fodder committee at the Adelaide Show. I am very honoured to be involved with both groups as a non-practicing agronomist or farmer: the only one without some land to actually grow a crop. Through these associations I hope to promote both groups and develop strong links to high-light the value of crop production in our state and publicise the innovation and passion of grain and fodder producers.

Report on the conference Plant Biology 2019: Crop Society

I had the privilege of attending Plant Biology 2019 in San Jose, California, an event hosted by ASPB (American Society of Plant Biologists) which had over 1400 attendees. Overall the conference had a range of interesting topics. One that was particularly interesting was a symposium on the future of agriculture. A speaker from a company called Impossible Foods talked about their latest product called the Impossible Burger: a burger that is the same taste and nutrition as a beef burger, but completely sourced from plants. The most helpful symposium for my research was the section 'Plant Disease and Resistance Mechanisms'. A very important concept presented was the fact that there is a dynamic relationship in immune response signalling or symbiosis based on the nutrient status of plants. In other words, a plant is more receptive to symbiosis when it is deficient in nutrients but will trigger an immune response if it is nutrient-sufficient. This may have implications in my research on parasitic interactions between nematodes and plants; would the host plant behave differently under different nutrient levels?

I was selected for a talk during the symposia of 'Plant-Biotic Interactions' to present my PhD research on a novel discovery on interactions between cereal cyst nematode and wheat. This was an exciting opportunity because I was speaking to a range of international researchers working on similar plant-pathogen interactions. My presentation sparked the interest of several researchers and lead to insightful discussions which contributed to my project and understanding of the subject even further. Importantly, no other attendees had seen the results I presented, confirming that my discovery is indeed novel. I also presented an electronic poster that contained videos of my discovery. This was an even greater opportunity to talk one-on-one with some interested scientists. One of the event organizers, a leading professor in soybean cyst nematode resistance, was particularly excited by my poster and introduced me to several of his lab researchers. They showed me some exciting new results in gene expression within feeding sites of soybean cyst nematodes. These results directly corresponded to the physical and morphological results that I had presented, further reassuring me that my research provides new evidence for some well-known cyst nematode interactions.

I sincerely thank CSSA for the Duncan Correll travel award to attend this conference. It has helped me to disseminate my novel findings to an audience of international scientists within the field. Additionally, it has opened doors for me to build bridges for future collaborations and research opportunities.

A good looking pea crop north of Balaklava that will now not produce a grain crop worth harvesting (Craig Davis)

ROSEWORTHY TRIAL TOUR

Photos by Craig Davis

Rhiannon Schilling (Adelaide University) provided an in-depth look at the national subsoils project looking at high pH, sodicity, boron among other constraints.

Utilising residual deep moisture may not be the reason why some varieties perform better with hostile subsoils. They may just be more efficient at using the available surface moisture.

On going work assessing new breeding lines & traits will hopefully lead to better adapted wheat & durum lines for commercialisation. A huge array of data is being collected & analysed and will hopefully keep the Crop Science Society newsletter populated for many editions to come.


Impact of crop type, seed bed utilisation (row spacing x furrow width) & herbicide treatment on ryegrass seed set.

Wheat sown as zero-row (prespread) showing poorer competitive effect compared to barley.

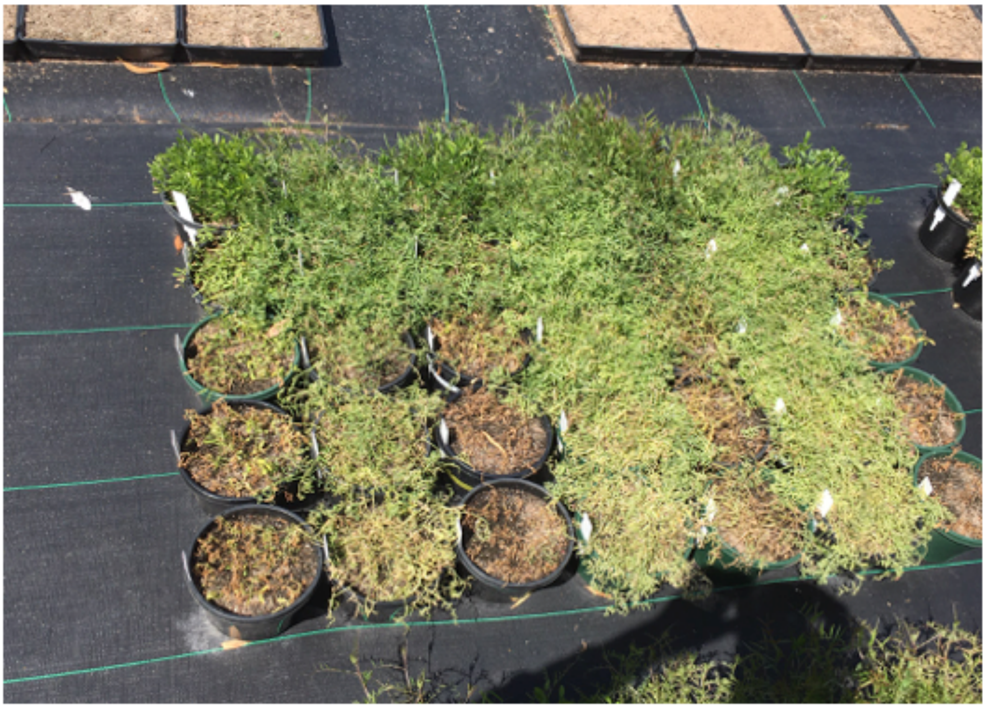
Barley on wide rows (15”). Narrow furrow spread.


Glen McDonald’s crop establishment project was inspected looking at effect of seed separation on crop establishment, weed competition & crop yield. Singualised (left) and standard (right)

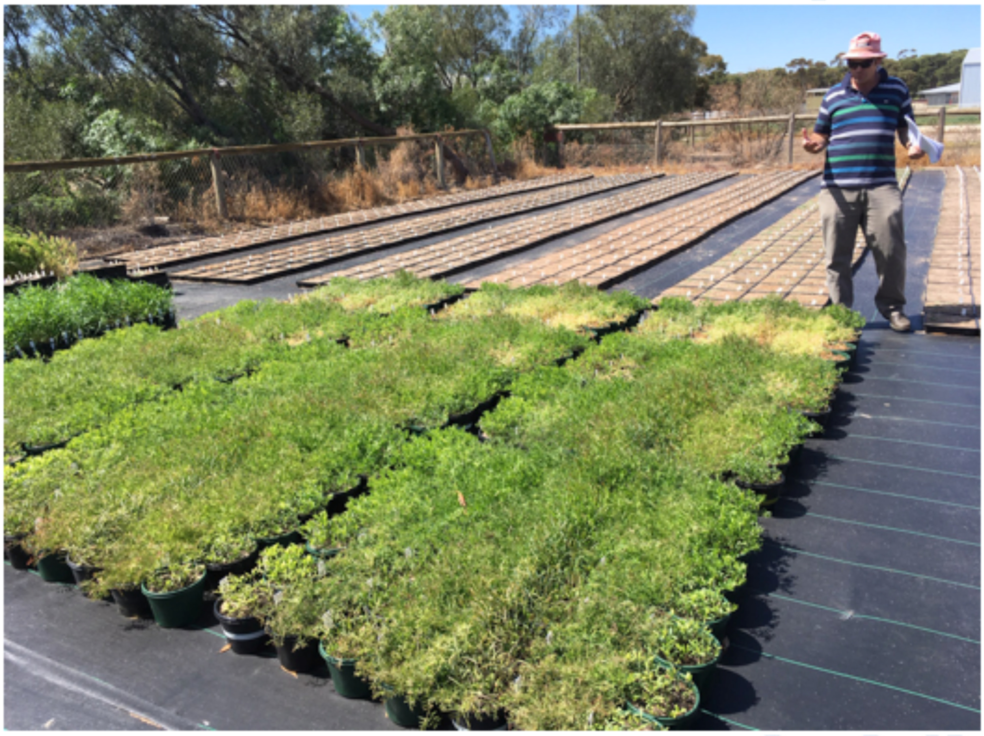
Barley grass has emerged as an increased threat to cropping & pasture systems due to delayed emergence & increased resistance. Understanding the dormancy will be as important as understanding the level of herbicide resistance present.

Barley grass, brome grass, ryegrass, turnip, statice, bedstraw, bifora, milk thistle, tares & marshmallow all being investigated under wheat & lentils for crop competition, seed set & harvest capture. Ben Fleet & Dan Peterson.

Ben Fleet & Dan Peterson (Adelaide University) provided valuable information regarding the fate of ryegrass captured with chaff lines & chaff decks.



This particular set looking at clopyralid tolerance.



Herbicide tolerance of 7 vetch/tare species.

Management of early sown wheat: Development patterns of early sown wheat cultivars in the Mid-North of South Australia

Dylan Bruce[1], Kenton Porker[2], Sarah Noack[3], James Hunt[4], Bonnie Flohr[5]

[1]South Australian Research and Development Institute, 70 Farrell Flat Rd, Clare, SA, 5453
[2]South Australian Research and Development Institute, Hartley Grove Urrbrae, SA, 5064
[3]Hart Field-Site Group, 155 Main North Rd Clare, SA, 5453
[4]Department of Plant, Animal and Soil Sciences, AgriBio Centre for AgriBiosciences, 5 Ring Rd La Trobe University, Bundoora, VIC, 3086
[5]CSIRO Agriculture and Food, Waite Rd Urrbrae, SA, 5064

Abstract
Flowering time is a key determinant of wheat grain yield. As farm size increases, slow developing wheat cultivars enable growers to start sowing earlier, resulting in a greater proportion of the total sown area to flower during the optimal period. In 2017 an experiment consisting of nine cultivars and four times of sowing was established in Hart, South Australia, to assess the development and yield of newly released and unreleased winter and spring wheat cultivars. Due to its superior yield and stable flowering date, the long season winter cultivar Illabo was most adapted to the growing conditions at Hart from wide sowing windows (four weeks). All winter cultivars had stable flowering times (flowered within a 23 day period across all times of sowing), except for DS Bennett which flowered after the optimum period from early May sowing. While spring wheats sown at the optimal time were high yielding, yield and flowering dates were unstable over wide sowing windows with flowering dates spanning one month. The slow maturing spring cultivar LPB14-0392 also yielded well at Hart, although it does possess a unique development and flowering pattern that requires further investigation.

Keywords
Winter wheat, optimal flowering period, double ridge, yield stability, water stress

Introduction
Wheat production in South Australia currently accounts for 58% of the state's total winter crop tonnage (ABARES, 2018). Growers are sowing earlier in response to reduced autumn rainfall and increasing farm size (Flohr et al., 2018, Fletcher et al., 2016). Sowing date and cultivar development type influence the time at which wheat flowers, and are therefore important determinants for grain yield. Crops that flower too early have increased risk of frost damage, while crops that flower too late have an increased risk of exposure to higher temperatures and water stress. Crop development of wheat is under strong genetic control (e.g. temperature accumulation, photoperiod sensitivity, vernalisation sensitivity and earliness *per se* genes). The most widely grown cultivars in South Australia are mid-fast developing spring wheat cultivars that have limited photoperiod and vernalisation sensitivity, and rely on temperature accumulation alone for phenological progression (Eagles et al., 2009). If these cultivars are established prior to April 20 they are under unsatisfactory frost risk at flowering. Therefore, growers are restricted to a narrower window to sow their crop in order for it to flower during the optimal flowering period (OFP) (Flohr et al., 2017). In order to sow any earlier with success, growers need cultivars in which development is slowed by photoperiod or vernalisation (Hunt et al., 2019).Winter cultivars have a vernalisation requirement, meaning they need exposure to a period of cold temperatures in order to progress from a vegetative to a reproductive growth phase in their life cycle. Similarly slow developing spring cultivars have sensitivity to day length, where the transition to reproductive development is prolonged by short-day conditions (10 hr or less light) (Harris et al., 2016). This transition is signalled by the double ridge (DR) stage in wheat, marking the occurrence of floral differentiation. Following DR is the terminal spikelet (TS) stage, marking the completion of the spikelet initiation phase in wheat. Cultivars with suitable sensitivities to vernalisation and photoperiod that are adapted to early sowing in low to medium (<350 mm and 350-500 mm, respectively) annual rainfall environments in South Australia have not yet been identified.

The aim of this experiment was to explore the variation in crop development of newly released and unreleased slow developing wheats and identify the most suitable development types for the Mid North of South Australia.

www.agronomyaustralia.org/conference-proceedings

Methodology

An experiment was sown at Hart in 2017 as a split-block design containing four replicates of nine cultivars (Table 1), at four times of sowing [ToS (14th March, 31st March, 18th April and 3rd May)]. Cultivars were selected based on the differentiation of their development type from one another. Three plants were removed from each plot on frequent intervals in replicate one to determine their developmental growth stage and prepared for dissections using the protocols of Kirby and Appleyard (Kirby, 1984). The apical meristem was then examined under a digital Wi-Fi compound microscope (Leica ICC50 W). An image of the apex was taken and the development stage determined using the Waddington Scale (Waddington et al., 1983). Key floral development stages measured included the double ridge (DR) and terminal spikelet (TS) stages, while anthesis date was measured in the field when 50% of spikes in the plot had flowered. From 15 minute interval recordings of air temperature at the Hart Field-Site, cardinal air temperature and adjusted growing degree days [°Cd ($TT = \sum ((T_{min} + T_{max})/2) - T_{base})$] were calculated for each ToS, where $T_{base} = 0°C$, $T_{optimal} = 23°C$ and $T_{max} = 37°C$ as per Flohr et al. (2018). Vernal days from sowing to DR were also calculated using $T_{base} = -1.3°C$, $T_{optimal} = 4.9°C$ and $T_{max} = 15.7°C$ (Flohr et al., 2018, Porter and Gawith, 1999). The first three ToS were irrigated with the equivalent of 10 mm of rainfall post-sowing to ensure plant emergence would occur. All plots were mechanically harvested for grain yield. Grain yield is reported at 12.5% moisture.

Table 1. Categories of wheat cultivars based on their development type selected for the experiment at Hart in 2017.

Habit	Cultivar	Development Speed
Winter	DS Bennett	Slow-mid
	Illabo	Mid-fast
	Longsword	Fast
Spring	LPB14-0392	Slow
	Cutlass	Mid
	Trojan	Mid-fast
	Scepter	Fast

Results and Discussion

Analysis of sowing time and development

An annual rainfall of 330 mm was received at Hart in 2017, 191 mm of which fell during the growing season (April to October). This was considerably lower than the long term average of 407 mm of annual and 297 mm of growing season rainfall. Six frost events (temperatures reaching 0°C or below) were also recorded between the 18th and the 29th of August. Winter cultivars required a greater number of vernal days, but a lower number of calendar and accumulative degree day to reach DR at later ToS (Figure 1). This result is due to the vernalisation requirements of the winter cultivars saturating faster in the cooler minimum temperatures of winter, compared to autumn sowing dates. Genotypic differences were observed among the winter wheats in terms of their development at Hart. The calendar and growing degree days taken to reach DR and TS varied both between sowing dates and within cultivars. These results confirm that there is enough exposure to low temperatures at Hart to allow transition from the vegetative to reproductive growth phase in a range of cultivars. This allows the successful planting of fast to slow winter wheats across a range of autumn sowing dates at Hart.

The time to TS correlated with the time to flower in winter cultivars, whereas this is not the case in the spring types. For example, from May sowing dates Cutlass and Scepter reached TS at a similar time, but Cutlass flowered 12 days later than Scepter. This is likely due to the stronger photoperiod requirement of Cutlass extending the reproductive phase. It was also observed in the earlier ToS that the spikelet initiation phase (time between DR and TS) increased as the vegetative phase (time to DR) increased in all winter cultivars. The extension of the duration of spikelet initiation found among the cultivars with a vernalisation requirement may be influenced by their level of photoperiod sensitivity. However, Longsword a photoperiod insensitive winter wheat responded similarly to the photoperiod sensitive winter wheat DS Bennett, an observation that requires further investigation. This result could indicate these phases are not independent of each other or under another developmental control like earliness *per se* (Eps) genes. ToS had little influence on the length of the stem elongation phase in winter wheats, largely due to the modulation from vernalisation in previous development phases. Meaning the spike development phase was exposed to similar environmental conditions in both sowing scenarios. Cultivars also differed in length of the late spike development phase (time between TS and anthesis). Spring cultivars had a longer spike development phase compared to winter wheat.

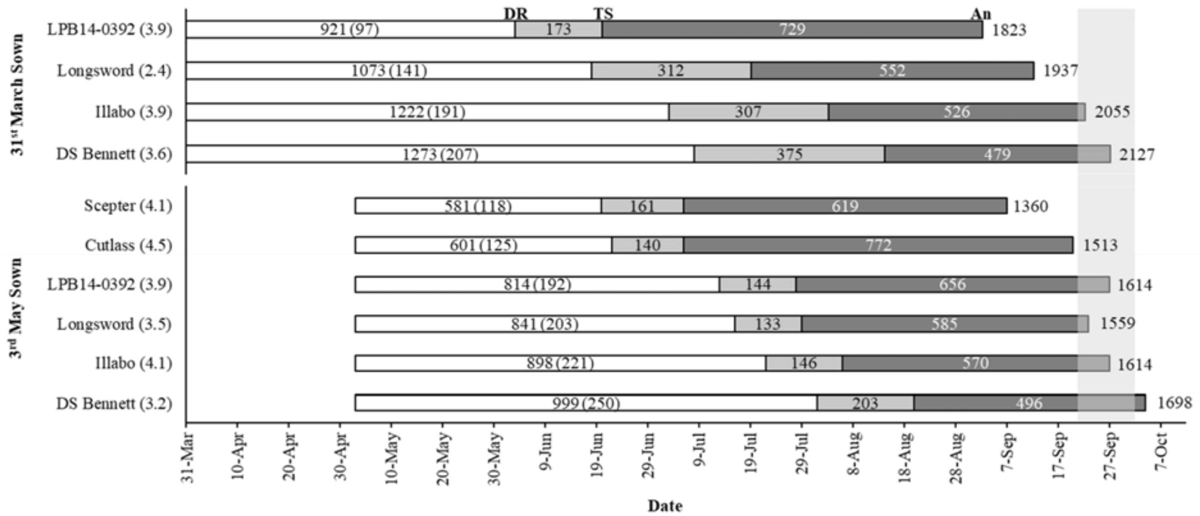


Figure 1. Developmental patterns of spring and winter wheat cultivars sown at Hart SA, in 2017. Numbers written in brackets next to the cultivar's name indicates yield in t/ha (LSD = 0.37). White area is calendar days from sowing to double ridge (DR), light grey area is calendar days from DR to terminal spikelet (TS) and the dark grey area is calendar days from TS to flowering (An). Number written without brackets inside graph is accumulative degree days °C and number written within brackets is vernal days to reach DR. Number at the end of the graph indicates total accumulative degree days °C to reach anthesis. Vertical light grey box is the optimal flowering period for Hart as per Flohr et al. (2017, defined as 21st September to 2nd October).

The mid-fast winter Illabo was able to flower during the OFP for Hart across the multiple ToS, whereas Longsword flowered too early from the early ToS and DS Bennett flowered too late from the later ToS. The photoperiod sensitive spring cultivar Cutlass also flowered too early from pre April 20 sowing (data not presented). The slow spring cultivar LPB14-0392 showed a unique development pattern. The temperature accumulation requirement for LPB14-0392 to reach DR was met at 921 degree days from early sowing, and 814 from the later sowing date. However, once reaching DR the spikelet initiation phase and stem elongation phase were extended. This cultivar also reached DR and flowering earlier than Illabo when sown early. In contrast, at the later sowing LPB14-0392 reached DR earlier and flowered later than Illabo. Despite these differences both LPB14-0392 and Illabo produced similar yields. This cultivars unique flowering behaviour and yield ability at Hart will require further research as its physiological requirements and response to environmental factors are not completely understood.

Grain Yield

The selected winter cultivars produced their highest yields in 2017 during the OFP for Hart (Flohr et al., 2017), whereas this period appeared to be too late for the faster maturing spring cultivars. The highest yielding cultivars sown on the 31st of March were LPB14-0392 and Illabo at 3.9 t/ha. However, both spring cultivars Cutlass and Scepter yielded 4.5 and 4.1 t/ha, respectively, when sown at their optimal sowing time (3rd of May). The slow maturing spring cultivar LPB14-0392 was able to maintain a yield of 3.9 t/ha when sown four weeks later. Early sowing of slower maturing cultivars were able to remain in a vegetative growth phase for a longer period than spring cultivars. This allowed for the development of a deeper root system to access stored soil moisture down the soil profile from the previous years and summer rainfall, and moisture closer to the surface when it became available later in the season (Lilley and Kirkegaard, 2016).

Conclusion

This data demonstrates breeders have developed winter wheats with an appropriate development pattern for earlier sowing at Hart in the Mid North of South Australia. Illabo appears to be the best adapted winter cultivar to growing conditions at Hart in the Mid-North region. This cultivar was able to maintain a stable flowering time close to the OFP, while also providing yield stability when sown in early – mid April. LPB14-0392 is another cultivar showing high yields from April sowing. Fast developing spring wheat

Scepter and photoperiod spring wheat Cutlass are not suited to pre April 20 sowing. The unique development pattern of LPB14-0392 suggests different combinations of crop development genes may allow for the use of spring types to explore earlier sowing opportunities than previously thought. This needs to be investigated further through additional experimentation across multiple growing seasons, in order to achieve a comprehensive analysis of these cultivars and others that may be suitable to the growing conditions at Hart.

Acknowledgements
This research was funded by GRDC project 9175069 and the SAGIT funded regional internship in applied grains research (HART115).

References

ABARES. 2018. *Australian crop report* [Online]. Canberra: Australian Bureau of Agricultural and Resource Economics and Sciences. Available: https://doi.org/10.25814/5c00a3822b438 [Accessed].

EAGLES, H. A., CANE, K. & VALLANCE, N. 2009. The flow of alleles of important photoperiod and vernalisation genes through Australian wheat. *Crop and Pasture Science,* 60**,** 646-657.

FLETCHER, A., LAWES, R. & WEEKS, C. 2016. Crop area increases drive earlier and dry sowing in Western Australia: implications for farming systems. *Crop and Pasture Science,* 67**,** 1268-1280.

FLOHR, B. M., HUNT, J. R., KIRKEGAARD, J. A. & EVANS, J. R. 2017. Water and temperature stress define the optimal flowering period for wheat in south-eastern Australia. *Field Crops Research,* 209**,** 108-119.

FLOHR, B. M., HUNT, J. R., KIRKEGAARD, J. A., EVANS, J. R., TREVASKIS, B., ZWART, A., SWAN, A., FLETCHER, A. L. & RHEINHEIMER, B. 2018. Fast winter wheat phenology can stabilise flowering date and maximise grain yield in semi-arid Mediterranean and temperate environments. *Field Crops Research,* 223**,** 12-25.

HARRIS, F., MARTIN, P. & EAGLES, H. A. 2016. *Understanding wheat phenology: flowering response to sowing time* [Online]. GRDC. [Accessed].

HUNT, J. R., LILLEY, J. M., TREVASKIS, B., FLOHR, B. M., PEAKE, A. & FLETCHER, A. L. 2019. Early sowing systems can boost Australian wheat yields despite recent climate change. *Nature Climate Change,* 9**,** 244-247.

KIRBY, E. J. M. 1984. *Cereal development guide,* Kenilworth, Arable Unit, National Agricultural Centre.

LILLEY, J. M. & KIRKEGAARD, J. A. 2016. Farming system context drives the value of deep wheat roots in semi-arid environments. *Journal of Experimental Botany,* 67**,** 3665-3681.

PORTER, J. R. & GAWITH, M. 1999. Temperatures and the growth and development of wheat: a review. *European Journal of Agronomy,* 10**,** 23-36.

WADDINGTON, S. R., CARTWRIGHT, P. M. & WALL, P. C. 1983. A Quantitative Scale of Spike Initial and Pistil Development in Barley and Wheat. *Annals of Botany,* 51**,** 119-130.

Genetic opportunities in exploiting genotype × row spacing for rainfed wheat

Greg Rebetzke[1], Kathryn Bechaz[2], David Smith[3], Tina Rathjen[1], Neil Fettell[4], Andrew Fletcher[5], Cathrine Ingvordsen[1]

[1] CSIRO Agriculture and Food, Black Mountain Science and Innovation Park, Canberra, ACT, 2601, greg.rebetzke@csiro.au
[2] NSWDPI, Yanco Agricultural Institute, Yanco NSW 2703
[3] CSIRO Agriculture and Food, Yanco Agricultural Institute, Yanco, NSW 2703
[4] Central West Farming Systems, 1 Fifield Rd Condobolin, NSW 2877
[5] CSIRO Agriculture and Food, Centre for Environment and Life Sciences, PMB 5, Wembley, WA 6913

Abstract

Optimising row spacing is a key target to better manage limited soil water, weeds and optimise radiation interception to increase biomass and yield in rainfed systems. Studies to date indicate little opportunity with current wheat varieties to exploit genetic improvement when targeting variable wheat populations and genotype × row spacing interaction. The exploiting of novel genetics offers potential to develop synergies with specific farming systems not routinely selected for in commercial breeding programs. Early vigour genes bred into wheat through novel recurrent selection methods show promise of more rapid leaf area development, a trait by which crop water-use and water productivity may be improved in wide row situations. Narrower row spacings were associated with significantly greater light interception, grain yield (3.6 vs 2.9 t/ha) and total biomass (10 vs 7.7 t/ha). Commercial bread and durum wheats, and triticales intercepted significantly less radiation than high vigour-selected wheats under wide row spacing. Comparisons between low- and high vigour selected lines indicated a small increase in yield with greater vigour in wider rows. Identification of high-yielding lines with greater early vigour indicate potential to select wheats with adaptation to wider row spacing.

Key Words
Breeding, pre-breeding, genotype × management interactions, water productivity

Introduction

Adoption of no-till and stubble retention farming systems has seen increased interest in wider row spacings for winter cereals including wheat. Capacity to increase row spacing is seen as a simple tool for growers to better manage stubble loads, increase sowing speeds, and capacity for inter-sow rows. However, wider rows have been associated with greater weed incidence owing to reduced crop competition (Borger et al., 2017). Reducing row spacing is associated with increasing grain yields for wheat in rainfed systems in WA (Borger et al., 2017) and southern NSW (Scott et al., 2013), and these increases are consistent with reports on increasing grain yields with reductions in row spacing elsewhere (e.g. the United States; Roth et al., 1984; Johnson et al., 1988). The influence of row spacing on soil water use and water productivity is less well-understood with growers using wider row spacings as a water conservative strategy in low-yielding regions of the wheatbelt (less than 3 t/ha) to reduce leaf area/biomass per unit sown area. In productive regions with higher in-crop rainfall, wider spacings may limit yield potential due to greater water evaporation and reduced leaf area.

Row spacing studies are typically undertaken using commercially available wheat varieties bred for average performance across a range of potential farming systems and environments (Cooper et al., 2001; Rebetzke et al., 2014; Scott et al., 2013). In turn, genotype × row spacing interaction effects are small to non-existent suggesting little benefit in targeting selection of spacing-adapted wheats in breeding for wider rows. The potential exists to focus selection on alleles for improved performance from genetic resources less used in commercial breeding programs. For example, repeatable genetic variation under strong additive genetic control exists for seedling or early leaf size (Rebetzke and Richards 1999). More vigorous wheats producing greater leaf area early in the season may have potential to better exploit increasing row spacing and greater efficiency in soil water management. A long-term S1 recurrent selection breeding program initiated from intercrossing across 30 globally-diverse high early vigour wheat genotypes has delivered wheat germplasm producing greater early leaf area (Zhang et al., 2015). The development of these genotypes was based solely on selection for wider leaves in seedlings sown after standardising to a common seed weight (Rebetzke and Richards, 1999). Cycle 3 derivatives have been top-crossed with Australian commercial wheats to improve agronomic quality whilst retaining greater early vigour. This paper reports on experiments aimed at assessing the performance of high- and low-selected vigour sister lines grown at a common sowing density at two row spacings.

Methods

A diverse set of cereal entries including 28 wheat varieties with breeding lines selected for high and low vigour (recurrent selection derived), and triticale varieties were sown under irrigated and rainfed conditions at the Yanco Managed Environment Facility in 2017. Target plant density was 140 plants/m^2 sown at either 25 cm row spacing, and between rows using GPS at 12.5 cm row spacing. Measurements were made of early leaf area and biomass, ground cover and light interception, anthesis biomass and then grain yield, spike number and biomass at maturity. Soil-water was also measured in the irrigated treatment in 2017. Entry × row spacing treatments were replicated three times in a split-block experimental design with row spacing as a whole plot and entries as a split plot factor. Data were analysed using Genstat 16 (VSN 2017). For analysis, entries were grouped and contrasts developed according to source i.e., high vs low vigour selections along with commercial wheat and triticale varieties.

Results and Discussion

Average plant number was the same (131 and 130 plants/m^2 and 128 and 132 plants/m^2) for narrow and wide row spacings, in irrigated and rainfed treatments, respectively. Light interception was significantly greater throughout vegetative growth with narrower row spacing (Table 1), reflecting the greater leaf area indices and better spatial arrangement of plants soon after emergence (data not shown). Despite the greater light interception, anthesis biomass and numbers of fertile tillers did not differ between wide and narrow rows. However, at maturity, grain yield was significantly greater with reduced row spacing and this result reflected increases in numbers of fertile spikes and final (maturity) biomass. The greater yields were associated with increased numbers of grains per unit area (i.e. m^{-2}) in narrow rows while seed size and harvest index were unchanged (Table 1).

Genotypic differences were large and statistically significant across row spacings for most measured attributes (Table 2). The relatively smaller grain yields in the low and high vigour selected wheats reflected that these lines were only 50% commercial genetic background, and that their development and selection was focussed on early vigour and agronomic quality (i.e. common heights and anthesis date) and not grain yield *per se*. That aside, selection for greater early vigour ('HV') was associated with greater leaf area at both row spacings, and these translated into significantly greater light interception for the high vigour-selected lines. Three high vigour selections produced an average 1.75 m^2/m^2 LAI area when averaged across both 12.5 and 25 cm row spacings (data not shown). These same high vigour selections intercepted *c.* 55% of radiation under wide rows at the first measurement time (09/08) highlighting a near-doubling of the light intercepted by the commercial wheat checks at the same spacing. Further, light interception of these wheat lines was as great, or greater, than triticale which is considered among the most vigorous of the winter cereals.

Table 1: Influence of row spacing on light interception (LI) and agronomic performance of wheats and triticales sown at 12.5 and 25 cm row spacing at the Yanco Managed Environment Facility in 2017.

Row Spacing	LI. 09/08 (%)	LI 25/08 (%)	LI 17/09 (%)	Anthesis biomass (g/m^2)	No. tillers (m^{-2})	Plant height (cm)	Grain yield (t./ha)	Maturity biomass (t/ha)	Harvest index	No. grain (m^{-2})	Seed size (mg)	No. Spikes (m^{-2})
12.5	44	60	77	624	349	68	3.57	9.96	0.361	8860	41	408
25.0	36	51	66	601	331	68	2.89	7.70	0.377	7170	41	359
Prob^A.	0.001	0.001	0.001	0.344	0.749	0.897	0.001	0.001	0.202	0.001	0.469	0.001

^{A} probability that row spacing means are statistically different

Comparisons between the wheat groups at the two row spacings indicates strong genotype × row spacing interaction with reductions in grain yield for all including the commercial wheats at the wider row spacing (Fig. 1). Among commercial wheats, bread wheat Suntop and to a lesser extent Axe and durum wheat variety Jandaroi were all reduced in grain yield with wider row spacing whereas variety Mace was well-adapted to both narrow and wider row spacing. The broad adaptation of Mace is consistent with its established broader adaptation across a wide range of farming systems. That aside, a number of high vigour selected wheats also performed well at both narrow and wide row spacings (Fig. 1) despite their selection for early leaf area alone.

Table 2: Genotypic differences in wheats (commercial bread and durum) and triticales for light interception (LI) and agronomic performance when sown at 12.5 and 25 cm row spacing at Yanco Managed Environment Facility in 2017. 'LV' and 'HV' represent low and high vigour selections, respectively.

Row spacing	Entries/ groups	LAI 27/08 (m^2/m^2)	LI. 09/08 (%)	LI 25/08 (%)	LI 17/09 (%)	Anthesis biomass (t/ha)	Grain yield (t./ha)	Maturity biomass (t/ha)	Harvest index	No. grain (m^{-2})	Seed size (mg)	No. spikes (m^{-2})
12.5	LV	1.30	45	60	79	6.27	3.43	9.45	0.362	8440	41	407
	HV	1.58	48	60	78	6.12	3.57	9.81	0.366	8499	42	371
	Comm.	1.31	44	58	81	6.79	4.23	11.6	0.373	10998	39	434
	Durum	1.07	34	51	66	5.49	2.48	9.54	0.316	5431	44	363
	Triticale	1.23	42	59	80	5.09	3.83	10.1	0.412	8646	48	394
25.0	LV	0.99	33	50	67	5.91	2.69	7.07	0.384	6612	41	348
	HV	1.39	46	59	70	6.21	2.85	7.90	0.365	6760	43	358
	Comm.	0.83	31	43	60	6.19	3.21	8.32	0.397	8153	40	351
	Durum	0.67	24	38	54	5.01	2.18	5.71	0.386	4712	45	239
	Triticale	1.21	25	54	65	6.51	3.35	8.10	0.414	7173	49	266
LSD		0.17	1	5	4	0.79	0.49	1.09	0.04	1202	1.7	44

The greater grain yields in the commercial wheats and triticale at wider row spacing reflected greater maturity biomass and harvest index. Whereas triticale produced fewer spikes and numbers of grains but larger grain size, while wheat varieties produced more grain but of smaller average size (Table 2).

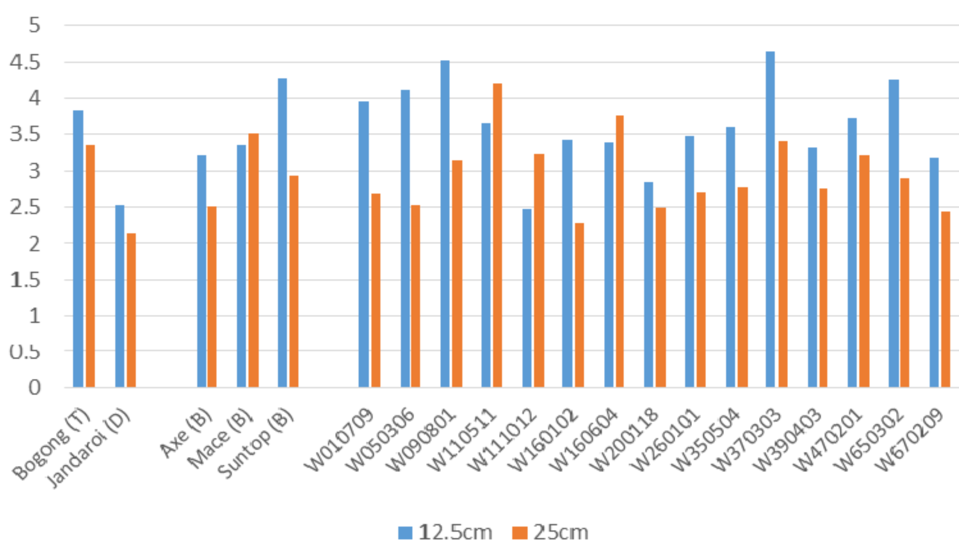


Figure 1: Grain yields (t/ha) for commercial triticale (T), durum (D), and bread (B) wheats, and a range of high- and low-vigour selected (W_) wheat germplasm evaluated in narrow (12.5cm) and wide (25cm) row spacings in two years at the Yanco Managed Environment Facility, Yanco NSW.

Conclusions

A clear understanding of the value proposition should underpin any long-term effort in breeding for new environments, new agronomic management or farming systems. The reduced vigour and conservative growth of current milling quality wheats may limit their potential and opportunities for greater biomass and yield to increase water productivity in no-till or stubble management systems utilising wide row spacing where crops are rainfed. Genes and low cost, high throughput selection methods are available to rapidly incorporate greater early vigour to improve performance in wide row sowings into commercial breeding programs.

Acknowledgments

We would like to thank the staff of the Yanco Managed Environment Facility for their excellent technical support. Thanks also to both reviewers for their excellent comments on the original manuscript.

References

Borger C, Reithmuller G, D'Antuono M (2017) Eleven years of narrow row spacing. GRDC Updates 2017

Cooper M, Woodruff DR, Phillips IG, Basford KE, Gilmour AR (2001) Genotype-by-management interactions for grain yield and grain protein concentration of wheat. Field Crops Research, 69, 47-67.

Johnson, J.W., Hargrove, W.L. and Moss, R.B., 1988. Optimizing row spacing and seeding rate for soft red winter wheat. Agronomy Journal 80, 164-166.

Rebetzke GJ, Richards RA (1999). Genetic improvement of early vigour in wheat. Australian Journal of Agricultural Research 50, 291-301.

Rebetzke GJ, Kirkegaard JA, Watt M, Richards RA (2014) Genetic vigour helps maintain superior leaf area development for wheat seedlings growing in uncultivated soils. Plant and Soil 377, 127-144

Roth GW, Marshall HG, Hatley OE, Hill RR (1984) Effect of management practices on grain yield, test weight, and lodging of soft red winter wheat 1. Agronomy Journal 76, 379-383.

Scott BJ, Martin P, Riethmuller GP (2013) Row spacing of winter crops in broad scale agriculture in southern Australia. NSW Department of Primary Industries.

VSN International (2017) Genstat for Windows 19th Edition. VSN International, Hemel Hempstead, UK. Web page: Genstat.co.uk

Zhang L, Richards RA, Condon AG, Liu DC and Rebetzke GJ (2015). Recurrent selection for wider seedling leaves increases early biomass and leaf area in wheat (Triticum aestivum L.). Journal of Experimental Botany 66, 1215-1226.