Early and Dry Sowing of Wheat

Research Impact Evaluation

April 2020

Published by:

Date	Role	Name
April 2020	Publisher	Harmeet Kaur, Impact Analyst (CSIRO - Impact Team)
	Reviewer	Jen Taylor, Research Director (CSIRO - A&F)

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<tr><td>THE CHALLENGE

For more information visit Background-Section 3</td><td colspan="4">Wheat is Australia's most valuable crop however the yields have plateaued since 1990, due to reduced rainfall and increasing temperatures in line with global climate change. Australian wheat production forecast has been lowest since 2007-2008 and biosecurity concerns have been rising.

There is need for farmers to sow crops earlier than they have been due to erratic opening rains to the season and larger farms relative to sowing machinery capacity and labour availability to sow the crop.</td></tr>
<tr><td>THE RESPONSE

For more information see:
3.2 CSIRO's response to challenges</td><td colspan="4">CSIRO has played a key role in the development, rapid uptake and improvement of Early and Dry Sowing programs to support the Australian wheat industry while addressing food security and quality challenge - one of the 6 major challenges that CSIRO is focused on. The work aimed at giving farmers the tools and practices needed to adapt to long-term climate-related changes.

Development & implementation of new management practices in the form of Early & Dry sowing programs has led to:
- increasing Australian wheat yields through application of new management practices and genetic solutions while adapting to the variabilities introduced by climate change (low rainfall + increased temperatures)
- addressing the needs of consolidated farms
- equipping farmers with required knowledge, awareness and implementation support to uptake new solutions with potential to benefit their bottomline while meeting market demands.</td></tr>
<tr><td>Timeline</td><td>Costs</td><td>FY2012-2013 to FY2017-2018</td><td>Benefits</td><td>FY2014-2015 to FY2023-2024</td></tr>
<tr><td>Financial Investment
(in 2019/2020 $$)</td><td>WDWL</td><td>$4,404,687</td><td>WODWL</td><td>$3,670,572</td></tr>
<tr><td rowspan="6">THE IMPACT</td><td colspan="4">Impact Type: For Summary of Impacts as per CSIRO's triple bottom line (TBL) Benefit Classification Impacts – Table 4</td></tr>
<tr><td colspan="2">Economic</td><td>Environmental</td><td>Social</td></tr>
<tr><td colspan="2">- increased yields
- New markets for cultivar seeds</td><td>-efficient management of larger farms
-adaptation to climate change</td><td>-farmer health and wellbeing
- resilience</td></tr>
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<tr><td>Business Unit(s)</td><td colspan="4">CSIRO Agriculture & Food</td></tr>
<tr><td>Prospective Future Impacts</td><td colspan="4">Underpinning research for the development of slow maturing cultivars. Development of new sowing systems (e.g. long coleoptile wheats for deep sowing) to take advantage of or create early sowing opportunities. Development of new tools for early sowing opportunities and address risk associated with frost</td></tr>
<tr><td>Underpinning Background Research</td><td colspan="4">Dual-purpose cropping work conducted by CSIRO before 2012</td></tr>
<tr><td>Confidence Rating in assessment</td><td colspan="4">Low-Medium

List of recommendations have been included that provide a snapshot of data requirements to support a more robust analysis, should the team decide to conduct a refresh of this impact assessment in 3-5 years.</td></tr>
<tr><td>Collaborators and sources to corroborate Impact</td><td colspan="4">GRDC, WANFTA, PLANFARM</td></tr>
<tr><td>Further Information</td><td colspan="4">Research Case-Study: Dr. Andrew Fletcher
Impact Evaluation: Dr. Anne-Maree.Dowd, Harmeet Kaur</td></tr>
</table>

This case study uses the evaluation framework outlined in the CSIRO Impact Evaluation Guide. The results of applying that framework to the Early and Dry Sowing case study are summarised in Figure 1.

Glossary and Notes

AGT	Australian Grain Technologies
BAU	Business as Usual
BU	Business Unit
BCR	Benefit-cost ratio
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CBA	Cost-benefit assessment
DPIRD	Department of Primary Industries and Regional Development
GRDC	Grains Research and Development Corporation
FY	Financial Year
NPV	Net present value
NSW	New South Wales
PV	Present Value
SA	South Australia
WANTFA	Western Australia No Till Farmers Association
WA	Western Australia
WDWL	With deadweight loss
WODWL	Without deadweight loss
WUE	Water Use Efficiency

Notes:

Unless mentioned otherwise,

- all $$ are in AUD
- all land area are in hectares

2 Purpose of case study and audience

The purpose of this case study is to assess the benefits generated through the development and implementation of early and dry sowing programs for wheat production and understand CSIRO's attribution to this work in Australia. CSIRO's early and dry sowing R&D has been undertaken with the view to protect Australia's wheat production against uncertainties posed by climate change, address the issue of plateaued yields, growing market demand and benefit farmers bottomline while enabling more efficient use of resources. With food security and quality being one of the 6 major challenges that CSIRO is focused on, the study highlights the spectrum of economic, environmental and social benefits arising for a range of stakeholders from this work at the macro (government at three levels/ public), meso (CSIRO and similar organizations like Grains Research and Development Corporation (GRDC)) and micro levels (farmers/ researchers/ social scientists).

The analysis provides an estimate of the benefit-cost ratio and the direct, indirect and potential future benefits of the R&D. The case study also discusses the key limitations and provides a list of recommendations to enable a more robust monitoring & subsequent evaluation in future assessments.

This report can be read as a stand-alone item or alongside other CSIRO Agriculture and Food evaluations to substantiate the impact and value of CSIRO's activities against funds and resources invested in this program. CSIRO as a service provider to the Government and Industry is highly focused on delivering value and impact through the scientific interventions that originate from research activities. The information is provided for accountability, communication, engagement, continuous improvement and future application purposes. The study is also intended to serve as a tool to underpin strategic investment decision making. The intended audience includes Business Unit Review Panels, federal, state and local governments, GRDC, wheat grower groups, CSIRO, universities and the general public.

3 Background

Wheat is Australia's most valuable crop, representing gross value of more than A$5 billion per year. Australia is one of the world's largest wheat exporters and accounts for 10% of global wheat exports. Our wheat yields more than trebled during the first 90 years of the 20th century but have plateaued since 1990. This is despite genetic improvements to wheat yield potential and the widespread adoption of improvements to agronomic practices such as summer weed management and no-till farming systems. Lower yields are majorly caused by reduced rainfall and increasing temperatures in line with global climate change. Australian wheat production forecast has been lowest since 2007-2008 and biosecurity concerns have been rising with Australia having to import wheat in 2018 for the first time in 12 years due to drought and unfavourable seasonal conditions.[1,2]

The UN Food and Agriculture Organization (FAO) estimates that agricultural production globally needs to increase at least 60% by 2050, to cater to the growing population and market demand[3]. Decreasing profit margins and increasing input costs are key issues. The sector demands effective solutions to increase wheat yields while enabling more efficient utilization of the available resources in this changing ecosystem.

3.1 Current Status-Quo and Challenges

For more than a century, wheat in Australia has been established on rains that fall in April and May and grows over winter to flower in an optimum period between September and October, depending on geographical location (See Figure 4). GRDC's Early Sowing Project (2013-2016) highlighted that wheat yield declined at 35kg/ha for each day sowing was delayed beyond the end of the first week of May using a fast-developing spring variety.

[1] http://www.agriculture.gov.au/abares/research-topics/agricultural-commodities/dec-2018/wheat

[2] https://research.csiro.au/graincast/changing-climate-has-stalled-australian-wheat-yields-study/

[3] FAO. 2017. The future of food and agriculture: trends and challenges

This optimum flowering period varies between regions.

Sowing date is a key agronomic management decision and crucial to growing a successful crop. If wheat is sown too early then it may suffer poor establishment, and the risk of frost is increased. If it is sown late there can be insufficient growth before flowering to achieve high yield and the risk of terminal drought and heat stress during grain filling. The optimum sowing date strikes a balance between these factors.

Time of wheat flowering = Function (establishment date, soil moisture, seasonal temperatures and cultivar development rate)

With changing weather patterns and declining yields, consolidation of farms and emerging risks, new interventions are needed to better address the current challenges being faced by wheat growers; some of which are outlined below:

Table 1: Challenges being faced by Australian Wheat Growers and Prospective Solutions

Challenges	Prospective Solutions
Climate change	• Effective sowing programs (scientific interventions) to address changing rainfall patterns and lower precipitation; solutions to minimise risks and challenges presented by climate change
• **Changing rainfall pattern** has made it more challenging to get crops sown on time so that they flower in the optimal window. Narrowing and shifting of the critical autumn month timeframes are resulting in thinning of the traditional sowing window. • **Lower precipitation:** Less reliable season-opening rains and hot and dry springs have led to a stagnation in national wheat crop yields. Research suggests lower rainfall accounts for 83% of the decline in yield potential, while temperature rise alone was responsible for 17% of the decline[4].	• management practices to address needs of consolidated farms - respond to variabilities introduced by climate change (low rainfall + increased temperatures) - enhance the efficiency with which crops convert available rainfall into grains while decreasing the environmental footprint - lift water use efficiency of grain-based production through improved pre-crop and in-crop management - solutions to lower risks and maintain the viability of wheat farms
Economic factors	
• **Farm Consolidation**: The area of crop sown per farm has increased due to consolidation and farmers seeking economies of scale for labour and machinery investments. This has meant that on a given farm the total amount of sowing to be done has increased and hence all the available area can't be sown within the optimal timeframe.	
Yields	• Response to the issue of plateaued wheat yields through: - new spring wheat cultivars with slowed development for higher returns from early and dry sowing programs - robust wheat varieties specifically for Australian needs - application of new genotypes and tailored sowing programs
• **Declining yield potential:** Potential yields in Australia, have declined by 27% since 1990, from 4.4 tons per hectare to 3.2 tons per hectare. This is attributed to a decrease in seasonal rainfall. • Research suggests that if the climate trend observed over the past 26 years continues at the same rate during the next 26 years, the national wheat yield will fall from the recent average of 1.74 tons per hectare to 1.55 tons per hectare in 2041, assuming that farmers continue to close the yield gap and reach 80% of yield potential. • Yield penalty from sowing outside the optimal window • Farmers' actual yields and bottom line are further restricted by economic considerations, attitude to risk, knowledge and other socio-economic factors.	
Other Risks	• Equipping farmers with required knowledge, awareness and implementation support to adopt new solutions in the form of sowing programs and management practices to benefit their bottomline and meet market demands.
• Cereal cropping has become riskier with dry spells at sowing, frost around flowering, and heatwaves and terminal drought during grain filling that are progressively increasing due to climate change. • The new fast-developing spring wheat cultivars incur unacceptable frost risk when sown early	

[4] https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.13604

3.2 CSIRO's response to challenges:

CSIRO in partnerships and collaborations with key collaborators like GRDC has played a key role in the development of Early and Dry Sowing programs to support the Australian wheat industry

The principal goals of this work have been to:

- #1 increase Australian wheat yields by encouraging growers to establish crops at a time that leads to flowering during the optimal period in their environment. In water-limited environments, the time at which wheat flowers is a critical determinant of yield.
  In addition, developing solutions to address the risks emerging as a result of new interventions, e.g. frost risk
- #2 investigate the potential for slow-developing cultivars sown much earlier than current practices to increase whole-farm wheat yields
- #3 address the needs of consolidated farms

Table 2: Early and Dry Sowing practices

What is CSIRO's intervention	How is the intervention effective?
Early Sowing *Sowing earlier (typically before May 1) with slow-developing cultivars into wet soil. A tactical approach that responds to wet sowing opportunities when they occur.*	• allows deeper root growth • improves access and better utilization of water • reduces evaporative and transpiration water losses • creates a longer growing season • creates opportunities to sow other crops towards end of the season thereby lowering overall risks
Dry Sowing *Placing seed into dry topsoil before the first autumn rains. A strategic approach that needs to be planned for every year*	• dry sowing allows a greater proportion of crops on a farm to germinate on the opening rain of the season with improved chances of increased yield • increases the window of opportunity for sowing because it uses stored soil water from summer rains • increases farm level wheat yields -via improved water use efficiency at the farm level • decreases heat stress during grain filling due to earlier flowering across a sowing program
New Management Practices (in addition to above)	• Both early and dry sowing have the effect of enabling crop establishment earlier across the whole farm with a net increase in yield and more efficient use of machinery and labour. The interventions have also helped with improved weed management, long fallow etc.
Note: Dry and Early sowing are related but not the same. Dry sowing is a special case of early sowing. The same cultivar are often used for both practices. However, when sowing very early, long-maturity cultivars should be used.	

4 Impact Pathway

INPUTS ► ACTIVITIES ► OUTPUTS ► OUTCOMES ► IMPACT

INPUTS

Funding

- CSIRO Business Unit funding and in-kind support
- External financial Investment by Grains Research & Development Corporation, AOF and Government

Research Capabilities

- Background knowledge and expertise in sowing programs and wheat optimal development and flowering times
- Access to high calibre, multidisciplinary capabilities (CSIRO and partners incl Universities)
- Access to infrastructure and resources to execute projects (e.g. on-site and off-site facilities, computer resources etc)

Translational Support

- CSIRO's strategic position and existing relationships that enables enabling liaison with different players (grower groups, consultants, collaborators etc) for uptake and adoption
- Strategic position and expertise of organizations like GRDC, to raise awareness, organize national workshops and provide necessary support to propel farmer training and implementation.
- Farmer contributions to trials

CSIRO Internal: A&F

CSIRO External: GRDC, WANFTA, Unis, Govt (all 3 levels), farmers

ACTIVITIES

RD&I Activities

- Ideation: defining, characterise and explain logic and conceptual models that underpin RD&I
- POC activities, incl but not limited to:
  - Pre-experimental modelling
  - Field trials
  - Demonstration Experiments
  - Development of improved assessments of the likelihood of risks and their management
  - Development of monitoring programs with farmers
  - Surveys
- Development of quantitative, semi-quantitative and/or qualitative analyses of intervention benefits

Collaboration Activities

- Engagement and support to wheat growers, partners, breeders

Education and Outreach

- Farmer information sessions and training programs
- PhD and Post Doc training

CSIRO Internal: A&F

CSIRO External: GRDC, WANFTA, Unis, Govt (all 3 levels), farmers

OUTPUTS

Research Solutions

- Early and Dry sowing programs including

-new management practices to enable more efficient use of water, machinery and labour

- identification of emergent risks and their management

- development of monitoring programs

- implementation strategies

External Network

- Platform for stakeholders to share research updates and develop practical on-farm recommendations
- Provision of scientific findings to growers, landowners, the community, industry and investors for informed decision making

Publications, Patents and Awards

- Publications
- Case Studies
- Awards
- Farmer survey results
- Analyses from industry survey data
- Quantitative, semi-quantitative and qualitative results from modelling and demonstration experiments

Postdoc recruitment

CSIRO Internal: A&F

CSIRO External: GRDC, WANFTA, Unis, Govt (all 3 levels), farmers, breeders

OUTCOMES

- **Uptake and adoption** of Early and Dry Sowing programs by wheat growers

Revenue

- Farm yield benefits and adaptation to climate change through uptake and adoption of new interventions
- Economies of scale for labour and machinery investments actualised by implementation of early and dry sowing programs on consolidated farms

Farmer Engagement and Capability Building

- Farmer consultancy, training and assessment programs with building a pipeline to scale returns from this scientific investment
- Farmers applying learnings from this program to other crops to attain similar benefits
- Feedback loop to incorporate earnings through the implementation of early and dry sowing programs by the farmers for continuous improvement.

Innovation Support

- Support to innovation sector, through dissemination of new knowledge and testing support. E.g. release of new long-season wheat varieties like "Longsword" and "Illabo" by AGT.
- Validation and **d**elivery support which has influenced breeding companies to retain mid and fast winter wheat varieties in their programs.

Stakeholder Integration

- Development of a platform for different stakeholders to increase the exchange of information, share experiences and enhance learnings for the development of sustainable management practices.

CSIRO Internal: A&F

CSIRO External: GRDC, WANFTA, Unis, Govt (all 3 levels), farmers, breeders

IMPACT

ECONOMIC IMPACT

- National economic performance
  - The wider economic benefit at the national level through increased productivity and profitability of the farming sector (incl wheat growers and advisors)
  - Increased potential flow through to increased government taxation and royalty revenues
- Management of risk and uncertainty
- New markets for cultivar seeds
- Policies and programs

ENVIRONMENTAL IMPACT

- Adaptation to climate change
- Lowered environmental footprint of wheat production through more efficient utilization of resources (e.g. higher WUE)

SOCIAL IMPACT

- Health and wellbeing
- Resilience

CSIRO Internal: A&F

CSIRO External: GRDC, WANFTA, Unis, Govt (all 3 levels), farmers, public

FY2012-2013 to FY2017/2018

FY2014-2015 to FY2023/2024

Fig 1: Impact Pathway for Early and Dry Sowing Program

Impact Evaluation

CSIRO's research work on early sowing started in 2012. However, the dual-purpose cropping work that heavily underpinned this work started before 2004. Dual-purpose cropping is when a long season wheat crop is sown early and then grazed by livestock while still vegetative. After grazing, the crop is left to reach maturity and the grain is harvested. Dual-purpose cropping provides two income streams from the same crop and has been shown to be highly profitable in mixed farming systems. Dual-purpose cropping work provided foundation blocks for the Early and Dry Sowing research; however, due to the unavailability of financial and other relevant data, any related work conducted by CSIRO before 2012 has not been included in this evaluation.

CSIRO conducted active Early and Dry sowing research from FY 2012/2013- FY2017/2018. Due to the awareness and implementation support provided by CSIRO and other key players (including but not limited to GRDC, WANTFA, DPIRD etc), there was uptake and adoption of new practices by the wheat growers starting 2014.

For the purposes of this evaluation, we account for costs associated with the work in the period of FY 2012/2013-FY2017/2018. The benefits are assessed from FY 2014/2015 to FY 2023/2024 (Expost: FY 2014/2015 to FY 2018/2019; Ex-ante: FY 2019/2020 to FY 2023/2024).

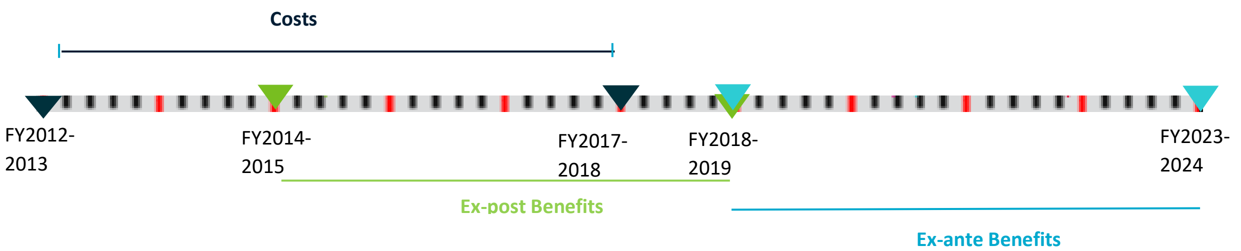

Fig 2: Early and Dry Sowing Program Timeline

Project inputs

CSIRO

- BU Funding
- Background knowledge and expertise in farming systems, sowing programs, wheat development required to obtain optimal flowering times
- Access to high calibre, multidisciplinary CSIRO capability
- Access to infrastructure and resources to execute projects (e.g. on-site and off-site facilities, computer resources etc)
- CSIRO's brand recognition, strategic position and existing relationships that enables enabling liaison with different players (grower groups, consultants, collaborators etc) for successful execution and implementation of this project.

Partners: GRDC, WANTFA

- External financial Investment by GRDC, WANTFA
- Strategic position and expertise of GRDC and WANTFA to raise awareness, organize national workshops and provide the necessary support to propel farmer training and uptake/adoption

Investments

- Cash and in-kind support[5] associated with all the work conducted by CSIRO and partners in the period of FY2012/2013 to FY2017/2018. This includes (but is not limited to) the following projects:

[5] Cash: Funding
In-Kind Support (CSIRO or Collaborators): a non-monetary contribution which includes CSIRO's overhead component

CSIRO Active Projects (under this program)

- WAN 00020 (year 1 of the project)
- WAN 00021 (years 2 - 6)
- CSP00178 Early sowing project

CSIRO only provides an in-kind contribution. These costs include salaries and experimental infrastructure. However, breakdown of these contributions are not available. Table 3 lists the input costs.

Table 3: CSIRO's input costs in Early and Dry Sowing Program

Contributor / type of support	FY2012/2013	FY2013/2014	FY2014/2015	FY2015/2016	FY2016/2017	FY2017/2018
WAN 00020 (R-03602-01 WANTFA Dry seeding into crop)						
CSIRO						
External partners	$53,100.00	$53,100.00				
Total cash	$53,100.00	$53,100.00				
CSIRO	$44,182.00	$44,182.00				
External partners						
Total in-kind	$44,182.00	$44,182.00				
WAN 00021 (R-05991-01 GRDC-WANTFA: WAN00021 Part II-Dry S)						
CSIRO						
External partners		$106,926.00	$106,926.00	$71,284.00	$71,284.00	$71,284.00
Total cash		$106,926.00	$106,926.00	$71,284.00	$71,284.00	$71,284.00
CSIRO		$49,685.00	$49,685.00	$77,498.00	$77,498.00	$77,498.00
External partners						
Total in-kind		$49,685.00	$49,685.00	$77,498.00	$77,498.00	$77,498.00
*Includes CAPEX item purchased through the project using cash received, CAPEX item cost does not appear in the WBS financials						
CSP00178 Early sowing project (R-05389-01 GRDC CSP00178 Early Sowing Sthrn Grain R)						
CSIRO						
External partners		312,500	312,500	312,500	312,500	

CSIRO only provides an in-kind contribution. These costs include salaries and experimental infrastructure. However, breakdown of these contributions are not available. Table 3 lists the input costs.

Table 3: CSIRO's input costs in Early and Dry Sowing Program

Contributor / type of support	FY2012/2013	FY2013/2014	FY2014/2015	FY2015/2016	FY2016/2017	FY2017/2018
Total cash		312,500	312,500	312,500	312,500	
CSIRO		122,506	122,506	122,506	122,506	
External partners						
Total in-kind		122,506	122,506	122,506	122,506	
Overall Cash	$53,100.00	$472,526.00	$419,426.00	$383,784.00	$383,784.00	$71,284.00
Overall in-kind	$44,182.00	$216,373.00	$172,191.00	$200,004.00	$200,004.00	$77,498.00
Total in 2019-2020 $$ (Real Discount Rate 7%)	$156,213.63	$1,033,851.64	$829,773.45	$765,226.98	$715,165.40	$170,340.51
Overall Program Investment in 2019/2020 $$ without dead weight loss	**$3,670,572**					
Overall Program Investment in 2019/2020 $$, incl dead weight loss	**$4,404,687**					

Source: CSIRO

These funds were spent on conducting activities listed in the next section.

*Since the projects under the umbrella of Early and Dry Sowing work are mainly funded by the Australian and state governments, the cost of the funds used for the research program should reflect on the rest of the economy. If it is assumed that funding for this work has been obtained through income taxation, there will have been negative effects on the private sector in the form of deadweight loss. It has been argued by several authors that research costs should be increased by about 20% to reflect the deadweight loss of income tax-based funding, although many Australian cost-benefit studies omit it.

Activities

CSIRO has played a key role in driving the revolution of Early and Dry sowing for Australian farmers. There are a number of activities that underpin the establishment of these novel approaches as solutions for effective farm management and higher crop yields with the changing environmental conditions. CSIRO has been working with key partners i.e. other organizations conducting independent research in this space and growers to enable this shift.

A snapshot of the key scientific activities performed under the program umbrella are included in Fig 3 below:

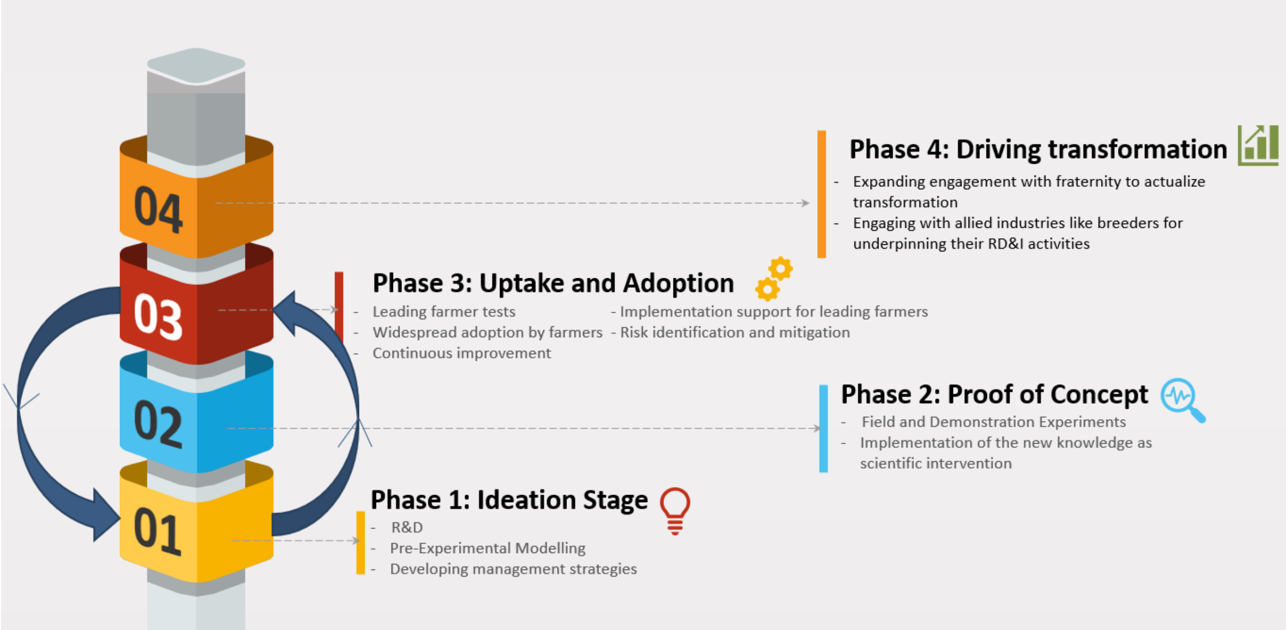

Fig 3: Phases in the development and implementation of Early and Dry Sowing work

The main wheat-producing areas in Australia that adopted the Early and Dry sowing interventions are highlighted within the red circle in Fig 4 below.

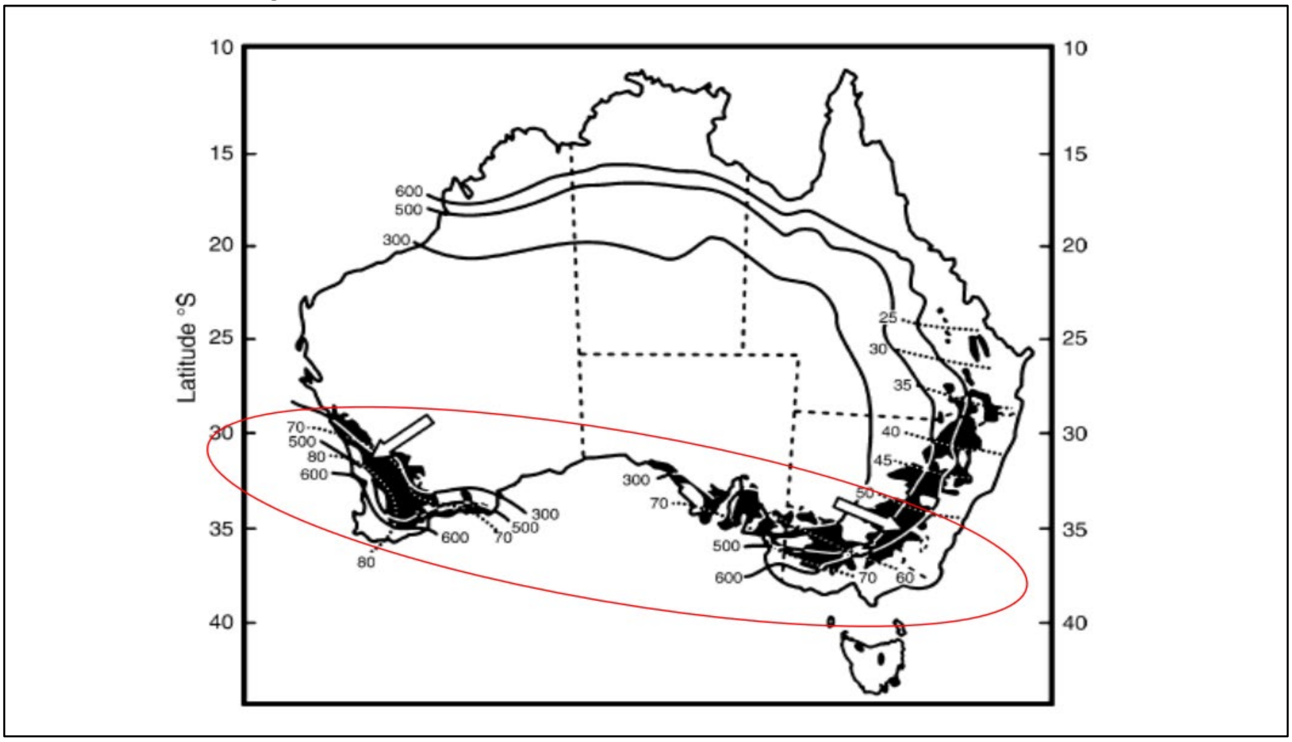

Fig 4: Main wheat-producing areas in Australia

Table 4: Stages of Early and Dry Sowing Work

<table>
<tr><td colspan="2">Stage 1: Ideation Stage
- R&D
- Pre-Experimental Modelling to extrapolate beyond the extent of trials and deliver relevant messages to a larger audience.
- Developing management strategies
CSIRO's role:
- conducted the pre-experimental and whole-farm modelling to determine the value proposition of dry sowing
- worked with Planfarm benchmark data set to identify the extent of dry sowing in WA as well as estimate the economic and physical drivers for whole-farm uptake of dry sowing.</td></tr>
<tr><td>Key Players: CSIRO, WANTFA, DPIRD, GRDC</td><td>Key Collaborators: PLANFARM</td></tr>
<tr><td colspan="2">Stage 2: Proof of Concept
- Field and Demonstration Experiments
- Implementation support for farmers
CSIRO's role:
- collaborated with WANTFA to conduct key demonstration experiments at WANTFA field days demonstrating the whole farm approach to dry sowing. These were demonstrated at a field day with ~100 farmers. The data was also presented at the Australian Agronomy Society.
- worked with DPIRD to conduct experiments to determine the effect of early-season drought on the growth and yield of wheat and canola.</td></tr>
<tr><td>Key Players: CSIRO, WANTFA, DPIRD, GRDC</td><td>Key Collaborators: PLANFARM</td></tr>
<tr><td colspan="2">Stage 3: Uptake and Adoption
- Leading farmer pilots
- Implementation by leading farmers
- Widespread adoption by farmers - Risk identification and mitigation
- Continuous improvement
- Participation in many regional projects with grower groups
- Organizing Annual Workshops
CSIRO's role:
- worked with Planfarm data set to identify the extent of dry sowing in WA and the whole farm economic and physical drivers of the uptake of dry sowing.
- presented an analysis of the economics of dry sowing to the Australian Association of Agricultural Consultants in WA.
- presented the results and contributed to discussions at field days[6]
- presented at > 5 Perth and regional crop updates papers.</td></tr>
<tr><td colspan="2">Key Players: CSIRO, WANTFA, DPIRD, GRDC</td></tr>
<tr><td colspan="2">Stage 4: Driving Transformation
- Necessary support to farming system/ regional groups.
- Expanding engagement with the relevant stakeholders to actualize transformation
- Engaging with allied industries like breeders for underpinning their RD&I activities
CSIRO's role:
This is for information ONLY. CSIRO not actively involved</td></tr>
</table>

Outputs

	New Knowledge
01	**Novel approaches to Early and Dry sowing programs** - The research has included field experimentation in conjunction with farmers, simulation modelling and field demonstrations to refine, validate and promote best-practice management techniques when early and dry sowing. - Understanding of higher yield and lower-risk benefits provided by early sowing practices - Utilization of slow-maturing varieties on larger farms; increasing cropping areas to exceed sowing opportunities and lower the frost risk associated with early sown and faster-maturing varieties.
02	**Identification of risks associated with recommended agro-practices and their mitigation** - Modelling studies have shown that dry sowing generates more benefits than risks for the farmers. - Modelling and experimental work have demonstrated that the key risks of early sowing (frost) can be overcome by matching sowing date with cultivar duration to minimise the risks.
03	**Development of monitoring programs to maximise benefits attained from the new practices.** - CSIRO worked with PlanFarm to monitor the extent of dry sowing in WA and the climate and farm type factors that influenced this. - CSIRO also analysed the Yield Prophet™ database to monitor the earlier sowing of cereal crops across Australia.
04	**Implementation Strategies** - Necessary support for implementing early and dry sowing practices, unlocking the potential for generating increased gains and adapting to the shift. - CSIRO led a national project to provide crop science, soil and climate modelling support to other projects and facilitate sharing of information and experience across cropping systems for benefit of everyone in the ecosystem.
	Other Outputs
05	**Publications** - Hunt, JR, Lilley, JM, Trevaskis, B, Flohr, BM, Peake, A, Fletcher, A, Zwart, AB, Gobbett, D, Kirkegaard, JA (2019) Early sowing systems can boost Australian wheat yields despite recent climate change. Nature Climate Change 9, 244-247. - Fletcher, AL, Robertson, MJ, Abrecht, DG, Sharma, DL, Holzworth, DP (2015) Dry sowing increases farm level wheat yields but not production risks in a Mediterranean environment. Agricultural Systems 136, 114-124. - Flohr, BM, Hunt, JR, Kirkegaard, JA, Evans, JR, Trevaskis, B, Zwart, A, Swan, A, Fletcher, AL, Rheinheimer, B (2018c) 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. - 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. - Kirkegaard, JA, Hunt, JR (2010) Increasing productivity by matching farming system management and genotype in water-limited environments. Journal of Experimental Botany 61, 4129-4143.
06	**Survey Results** - CSIRO worked with PlanFarm to analyse a benchmark survey of sowing dates and extent of dry sowing in WA. - CSIRO analysed the Yield Prophet database to monitor changes in cereal sowing dates.
07	**Awards** - The WUE initiative (CSIRO in collaboration with GRDC) won a Eureka Award in 2014. (This project is included as part of the early sowing work)[7].

[7] https://blog.csiro.au/eureka-theyve-done-it/

Outcomes

Farmer Uptake

01	**Uptake and adoption** Systemic change and standard setting leading to accelerated shift towards early and dry sowing in Australia.
02	**Revenue** - Modelling, farmer interviews and field trials demonstrate that adoption of dry and early sowing practices have potential to furnish wheat yield benefit of 170 -500 kg/ha without increase in likelihood of production risks, especially in a Mediterranean environment[8], [9]. This represents a potential of an additional 7.1 Mt annually for Australia despite climate change challenges [10]. - In an analysis of "Yield Prophet" wheat sowing dates have moved earlier by 1.6 days/year contributing an estimated $540 million/yr to the national wheat industry since 2010 - A 2017 survey showed 24% of growers from 14 shires across Western Australia started their sowing program before 26th April[11]. Prospects to utilise intercrops and crop variety mixtures in mechanised, rain-fed, temperate cropping systems[12]. - Approximately 16% of the WA grain growers are sowing the wheat dry (data mean of 2012., 2013, 2014). In 2018 it was estimated that 80% of crops in WA were sown in dry soil in anticipation for decent rainfall that didn't arrive until as late as June in some areas to the south[13]. - Opportunistic sowing of slow developing cultivars generated a further 19% more yield in certain cases.
03	**Farmer Engagement and Capability Building** - Farmer engagement and demonstration of yield benefits of early and dry sowing practices both at the individual paddock and whole farm scales. - The work has been presented to approximately 9191 growers and advisors at field days and updates, as well as grower group result booklets and social media (273 tweets with 14,728 engagements) - Feedback and implementation loop to inject continuous learnings from experience of farmers and implementors to further refine processes and procedures for benefit of all stakeholders - Targeted field experiments to suit local issues such as cultivar adaptation, disease and weed issues exacerbated by early sowing and its current levels of adoption - CSIRO is engaging with growers to provide consultancy and implementation support for new management methods including risk mitigation. - The benefits of the new knowledge systems, implementation and management solutions go beyond the farmers to include project proponents, State and local governments, land holders, interest groups and the general public.

Innovation Support

04	- Engaging with breeders (e.g. AGT. Other companies have also been indirectly engaged via field days and industry conferences) to provide support through new knowledge and testing services for the development of new varieties better suited for Australia's changing climatic conditions. - Leading wheat breeding company AGT has recently released a high yielding fast-maturing winter wheat variety – Longsword, suitable for early autumn sowing. This variety was tested and promoted by CSIRO in early sowing experiments. They have also recently released a new milling quality winter wheat variety "Illabo" marketed for dual purpose and early sowing. - Validation and delivery support which has influenced breeding companies to retain mid and fast winter wheat varieties in their programs.

[8] Fletcher AL, MJ Robertson, DG Abrecht, DL Sharma and DP Holzworth (2015)
[9] Agricultural Systems 136, 114-124
[10] Nature Climate Change 9, 244-247
[11] Fletcher A, R Lawes and C Weeks (2016). Crop area increases drive earlier and dry sowing in Western Australia: implications for farming systems.
[12] Crop and Pasture Science 67, 1268-1280.
[13] https://www.abc.net.au/news/rural/2019-02-08/history-shines-on-most-valuable-wa-harvest/10787676

05	Development of a platform for different stakeholders to increase the exchange of information, share experiences and enhance learnings for the development of sustainable management practices. This is becoming increasingly important with droughts and lower rainfall becoming a perennial feature of the Australian land sector. This focus and coordinated effort increase the likelihood of adoption of new solutions and concerted effort towards a systemic change for the benefit of all stakeholders for Australia's prosperity. Videos: https://www.youtube.com/watch?v=uVX6cMAzazU https://www.youtube.com/watch?v=y4bra9Q9BzI

Testimonials

Ron Osmond, GRDC	While early/dry sowing adoption has been driven by several contributors, CSIRO and the other projects participants have been instrumental in driving key research underpinning practice changes in earlier sown crops. CSIRO's ability to deliver and co-ordinate multi-disciplinary approaches to RD&E in this space have provided excellent industry outcomes, importantly engaging with industry, and including a demonstration of the potential financial impacts associated with early/dry sowing to support adoption.

Impacts

Table 5: Summary of project impacts using CSIRO triple bottom line (TBL) benefit classification approach

Type	Category	Indicator	Description
Economic	National economic performance	- increased yield - higher farmer profitability - better managed farming systems - higher government taxation and royalty revenues	Better yields enabled by scientific interventions that benefit farmers bottomline and enable more efficient use of resources. This converts to higher tax income for the government
	Management of risk and uncertainty	- decreased risk - higher farmer confidence	Scientific interventions provide improved risk management and better-informed decision making
	New markets for cultivar seeds	- new cultivars in the market tailored for early and dry sowing	Development of better slow or fast cultivars by breeders specific to Australia's needs
	Policies and programs	- policy and program decisions making	Potential for scientific advice and insights to policymakers in forthcoming years driven by climate change
Environmental	Adaptation to climate change	- increased yield - lifting Water use efficiency (WUE) - efficient use of resources, machinery and labour - removing barriers to farm consolidation through efficient management of larger farms	- Devising best practices based upon scientific findings and farmer experiences for overall better returns on farming investments as also highlighted in grower interviews covered in Table 8. - Higher outputs (yields etc) from the same level of resource investments in wheat production; better utilization of available water
	Lowered environmental footprint of wheat production through more efficient utilization of resources		
Social	Health and wellbeing	- higher farmer income - improved community wellbeing	Better yield and efficient management practices leading to better farmer wellbeing. See Table 8
	Resilience	- higher farmer confidence - reduced stress	Better risk management practices that lower threats of climate change and reduce farmer stress caused by variabilities

5 Clarifying the impacts

The work has generated new knowledge and provided implementation support for adopting agronomic practices to adapt to reduced autumn rainfall, extreme spring weather and increasing farm size for wheat growers throughout Australia. Enhanced wheat yield (demonstrating the potential for slow-developing cultivars) and new management practices are key outcomes of this work. With global climate change expecting to exacerbate and accelerate the occurrence of drought, the scientific community foresees greater adoption of this work by the wheat growers in the coming years[14].

It is important to note that the adoption of early and dry sowing practices and application of new management solutions is a systemic change and requires several interdisciplinary players to actualize benefits. Key stakeholders that have played a critical role in driving a change in age-old farmer practices in response to changing environmental and commercial ecosystems in this space include Funders, R&D Organizations, Industry (grower groups and consultants), Breeders and Government.

Key challenges associated with quantifying benefits through this work and driving this systemic shift include:

a) The program covered in this case study is a systems challenge. The work is not producing a tangible product or technology for which we can quantify commercial adoption and sales. Instead, it is producing new knowledge tailored to address the needs of the changing ecosystem in a focused and coordinated way.
   Although the sowing dates are measurable, with 12 million hectares of land being used for wheat production in Australia, the extent of adoption of new knowledge is by nature hard to measure. Also, the overall attainable benefits are highly dependent upon a number of complex factors (e.g. wheat varieties, rainfall, rainfall pattern, temperature etc). These factors can make quantification of benefits solely attributable to early and dry sowing practices difficult.
b) The footprint of implementation of new practices by farmers and deriving tangible benefits is being driven by a number of key players (e.g. GRDC, WANTFA, PLANFARM etc) thereby making it hard to estimate CSIRO's attribution.
c) While the work of the key players has helped drive a sizeable shift in the adoption of early and dry sowing practices, it is important to note that some farmers were already sowing early/dry before this work started. However, it is hard to quantify that due to lack of any supporting data.
d) The analysis is heavily based upon assumptions due to unavailability of benchmark data, ongoing and multi-phase nature of this work. None of the active organizations in this space is measuring the adoption rate over the years to assess impact.
e) It is hard to accurately assess the uptake and adoption levels and hence overall benefits as it is impractical to engage with all farmers adopting the new practices within key Australian regions. There were earlier attempts to achieve this data via remote sensing, but it has been unsuccessful. Any advancement and successful application of remote sensing techniques in this space require significant investment.
f) CSIRO's financial data on the underpinning research work undertaken before 2012 and benchmark research data is unavailable. This makes it hard to estimate the change and provides opportunities for CSIRO and partners for process improvement around monitoring and evaluation.

Counterfactual

As explained above, CSIRO is not working in isolation for actualizing this change in the ecosystem. However, CSIRO is one of the key organizations that pioneered this work for the benefit of Australia and contributed to more rapid uptake by growers and improvement of these practices. A part of the change would have happened even without

[14] https://www.nature.com/articles/s41558-019-0427-7?proof=true1

different organizations driving it, but the rate of this change and overall impact would have been much slower and lower.

Had CSIRO not been involved, there would be a lag of at least 5 years in realising the benefits from this work with at least 20-25% lower rates of adoption. This assessment is a result of inputs from growers, consultants and other stakeholders CSIRO engaged with for this impact evaluation (See Table 6 below). CSIRO's unique value-addition can be attributed to:

- CSIRO has a talented team of multi-disciplinary research and extension professionals enabling easy access to varied expertise. To execute this work successfully portfolio of skills including modelling analysis and experimentation were needed
- CSIRO's strategic position as Australia's innovation catalyst, national footprint and well-established collaborator network provide the ability to engage, obtain multiple sources of underpinning data & liaise with partners

Assessment of CSIRO's attribution

The focus of this CBA is to estimate the broader benefits generated from Early and Dry sowing work conducted by CSIRO in collaboration with its partners and to estimate the part of the net benefits attributable specifically to CSIRO.

Overall realised benefits for any farmland are a combination of:

a) early and dry sowing practices and other new management practices
   CSIRO's role: Active presence; explained above
b) application of new cultivars
   CSIRO's role: providing support to the cultivar companies with the new knowledge and testing

For the purpose of this analysis, CSIRO's attribution for (b) is considered 0. Also, since there is a spectrum of factors that underpin the benefits stemming from this work; attribution cannot be deemed solely contingent upon the funding contributions.

With many key factors and a broad array of actors, driving this change in the Australian ecosystem; to conduct an unbiased evaluation, Impact Team contacted wheat growers from key regions to provide their assessment of CSIRO's overall attribution; the results (>10 respondents) are covered in Table 6 below:

Table 6: CSIRO's attribution assessment for benefits generated from Early and Dry Sowing work

CSIRO's Attribution (this value has been calculated as an average of the attribution suggested by different responders)	20-25%
Counterfactual (this value has been calculated as an average of the counterfactual lag suggested by different responders)	5 yrs
Key comments from the respondents	
-the adoption may have happened anyway, but the work CSIRO and others have been involved with has helped facilitate the changes in seeding systems and on-farm experience where earlier sown crops performed much better, particularly in drier springs. - the work clearly demonstrated whole-farm $ benefits associated with early/dry sowing, well presented to influencers and farmers through the crop updates, AAAC PD, etc and involvement of respected partners in the project. - CSIRO pioneered developing the thinking behind this concept. Dry sowing has always been a practice; it was the understanding on the benefits of establishing crops as early as possible to allow greater root development and extract deeper water to achieve higher yields that CSIRO delivered. CSIRO provided handholding and expertise to growers for implementation of this practice, such as using the right varieties, establishing the appropriate plant population and matching the nutritional strategies. Their work helped with the development of the understanding of the crop phenology and demonstrated the whole package to the industry.	
Key Limitations - Every responder mentioned that due to a spectrum of contributing factors, CSIRO's attribution assessment is not very robust.	
Based upon the above data and to keep the analysis conservative, this case study will attribute total benefits as follows: **CSIRO – 10%** **Others – 90%**	

6 Evaluating the impacts

6.1 Evaluation Method

The study conducts this impact evaluation using a mixed-methods approach (i.e. identifying market and non-market benefits, using both quantitative and qualitative data), to provide an assessment.

A cost-benefit analysis was conducted for the period FY2012/2013 to FY2023/2024 to estimate the benefits of this work to Australia. Use of CBA enables comparison of benefits arising from CSIRO activities against the associated costs. The method provides a monetary measure of the current value for the program of work conducted (net present value) as well as relative benefits in comparison to costs for ex-post and ex-ante periods (Benefit Cost Ratio or Return on Investment Ratio). The CBA was conducted from an Australian perspective and only measures economic costs and benefits arising from and attributable to CSIRO's scientific interventions in Australia.

Table 7: Benefits assessment process snapshot

Step 1: Impacts being measured: Benefits attributable to CSIRO for generating yield gains for Australia due to adoption of Early and Dry Sowing practices for production of wheat. No credit has been taken for the support CSIRO provides for the development and implementation of new cultivars.	Table 8
Step 2: Extent of Impacts: For assessing the extent of the impact, the entire Australian wheat belt is considered for analysis.	Section 6.1.3
Step 3: Measuring the impacts:	Section 6.1.4 and 6.1.5
- Modelling Approach and Assessment Assumptions	Table 9
- CBA	Table 10 and 11
- Estimating costs	Table 3
-Externalities and flow-on effects on non-users - Determining distributional effects on users	Section 6.1.6
- Discounting	Section 7

6.1.1 Benefits measured (for CBA)

Table 8: Early and Dry Sowing practices – Benefits claimed for CBA

Impact	Interventions	Evidence of Adoption[15]	Benefits Reported		
			Simulations and field trials	**Yield Prophet[16]**	**Farmer Interviews**
i) Yield Gains	adoption of Early and Dry Sowing and management practices application of new cultivars	- wheat sowing dates have moved earlier by 1.6 days/year - 24% growers from 14 shires across Australia started their sowing program before 26th April. - Approximately 16% of WA wheat is sown dry.	- Yield gains (WA and SA): 0.4 to 1.0 t/ha: Mid-developing spring cultivars + Early Sowing - Field tests across Australian wheat belt have demonstrated higher yields of winter genotypes established prior to ~20 April compared faster-developing cultivars sown in mid-late May. Mean yield advantage: 0.4 -1.2 t/ha[17]. - Yield advantages identified by simulation: 0.5-1.2t/ha - Yield advantages identified by field experiments with near isogenic lines: 0.4-1.2 t/ha	- Reports an increase of 173% in the number paddocks sown prior to 1 May - Shift to Early sowing during the 2013-2015 has added 2.3 Mt to national wheat production per year, worth $540 million to the wheat industry	- Farmer A: Germination with an early sowing than the yield results can be easily increased to over 1t/ha above a late May sown crop. Capturing every drop of rain from early starts is a huge benefit with Early and Dry Sowing. The Illabo looks very competitive. More research on winter wheats would be helpful. - Farmer B: Haven't adopted Early and Dry sowing. Better management practices and weed control has contributed to higher yields. Dry sowing is more practical these days because of good chemistry like sakura. - Farmer C: Dry sowing has helped in getting sowing completed in a timely manner better machinery utilisation and water harvesting requiring smaller rainfall events to germinate. - Farmer D: Dry sowing has helped with better machinery utilization and less stress during the busy period. Adoption has allowed getting a day off over weekend; thereby adding to overall farmer wellbeing

[15] Fletcher A, R Lawes and C Weeks (2016). Crop area increases drive earlier and dry sowing in Western Australia: implications for farming systems. Crop and Pasture Science 67, 1268-1280.

[16] Flohr BM, JR Hunt, JA Kirkegaard, JR Evans, B Trevaskis, A Zwart, A Swan, AL Fletcher and B Rheinheimer (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.

[17] https://grdc.com.au/resources-and-publications/groundcover/ground-cover-supplements/ground-cover-issue-120-tactical-cereal-agronomy/dry-sowing-delivers-yield-benefits-over-time

6.1.2 Time Period

CSIRO's work on early sowing started in 2012. However, the dual-purpose cropping work that heavily underpinned Early and Dry sowing work started before 2004. For the purpose of CBA, we account for costs associated with the work in the period of FY 2012/2013- FY2017/2018. The benefits are assessed from FY 2014/2015 to FY 2023/2024 (Expost: FY 2014/2015 to FY 2018/2019; Ex-ante: FY 2019/2020 to FY 2023/2024).

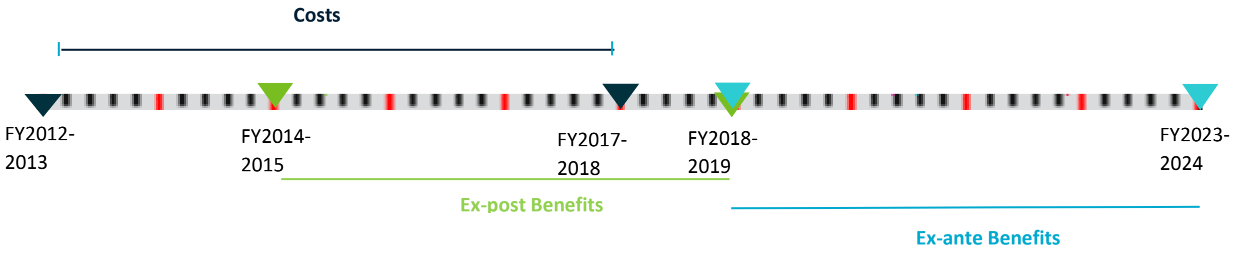

Fig 4: Timeline for benefits estimation of Early and Dry Sowing work

While the work of the key players has helped drive a sizeable shift in the adoption of early and dry sowing practices, it is important to note that some farmers were already sowing early/dry before this work started.

In any program, there are lags between the research and development and the realisation of benefits after adoption by the agronomy industry. Early and Dry Sowing practices started seeing adoption from 2014. However, by nature, the rate of adoption in subsequent years would be higher. On that basis, the benefits are measured from 2014 onwards. In the analysis, the costs are included from FY 2012/2013.

A conservative approach is adopted where it is assumed that benefits are measured to FY2023/2024. This is consistent with our prior assumption that in the counterfactual scenario the development and adoption of the work would be delayed by at least 5 years in the absence of CSIRO in this space.

Thus, the analysis involves a small component of *ex-post* analysis (relating to the costs and benefit in the period FY2014/2015 to FY2018/2019) as well as *ex-ante* analysis forecasting the benefits flowing from the research activities over the period FY 2019/2020 to FY 2023/2024.

6.1.3 Extent of Impacts

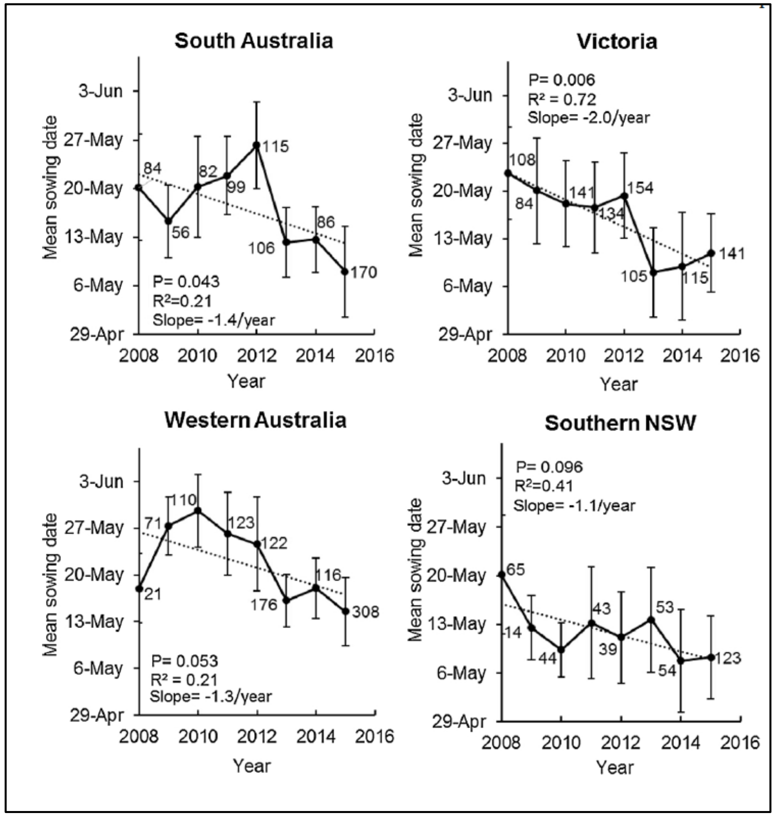

Fig 5. Change in mean wheat sowing dates for each of four states. taken from (Flohr *et al.* 2018c)

Fig 5 provides the changes in the mean wheat sowing dates for Australian 4 states for period of 2008-2016. Table 9 below provides modelling approach for CBA analysis.

6.1.4 Modelling Approach

To estimate the benefits of this work attributable to CSIRO, the following project case was used to model the estimated range of benefits as shown in Table 9 below:

Table 9: Modelling approach for estimating CSIRO's costs and benefits for Early and Dry Sowing program:

Parameter	Estimation
CSIRO Costs associated with Early and Dry Sowing program	All program costs, as provided in Table 3
Benefits attributable to CSIRO with the adoption of Early and Dry Sowing (for any year) *This estimates the additional wheat produced compared to normal sowing*	Total Area under wheat production (million hectares) in Australia * Adoption of Early and Dry Sowing for wheat by Australian growers in FY (of interest) * Yield advantage attributed to the adoption of Early and Dry sowing ONLY (t/ha) * Price / ton of wheat in FY (of interest) ($/t) * CSIRO's Attribution

Project assumptions

a) There would have been lag of atleast 5 years with the uptake of this work if CSIRO and partners had not been engaged in this work.

b) The farmers incur no additional costs with the adoption of the early and dry sowing program.

Farmer information sessions and training programs will involve opportunity costs of time to the farmers. Lack of precise information precludes the inclusion of these costs. On the other hand, the new management practices benefit the farmers through more efficient use of machinery and providing solutions to long-duration cultivars, improved weed management, long fallow etc. For purposes of this assessment, it is assumed that there are no additional costs associated with the adoption of new interventions.

c) Overall area under wheat production stays the same for the evaluation period. Wheat price for 2020-2023 remains the same and is average of price in the period of 2014-2019.

d) The real discount rate for the purpose of the CBA is assumed to be 7% per annum.

The focus of this analysis is to estimate the broader net benefit to Australia from the investment in the work, calculate the part of those benefits attributable to CSIRO and understand the payoff from this research work with respect to funding invested. It is, therefore, necessary to tease out CSIRO's costs and benefits—requiring a disaggregation of the positive externalities back to either CSIRO or to other contributors.

Adoption estimates underpinning CBA are given in Table 10 below.

Table 10: Adoption estimates for measuring impacts of Early and Dry Sowing work

<table>
<tr><th colspan="6">Parameter Description</th><th>Est</th><th>Reference/ Comments/ Assumptions</th></tr>
<tr><td colspan="6">1. Background Data for Benefits Estimation:
Australia's main Wheat producing areas are in Western Australia, New South Wales, South Australia, Victoria and Queensland.
Total Area under wheat production (million hectares):</td><td>12</td><td>https://www.agrifutures.com.au/farm-diversity/wheat/</td></tr>
<tr><td colspan="6">2. Annual adoption (in% of overall wheat area sown early and dry) of Early and Dry Sowing for wheat by Australian growers in FY 2014-2015 (this is base year)</td><td>1%</td><td rowspan="5">Key stakeholders in the ecosystem suggest the adoption rate 5-10% in this period (FY 2014/2015 to FY 2018/2019). Analysis based upon an estimate of 1%-5% to support conservative analysis.

GRDC's dry sowing data reports on an average 16% of wheat area was sown dry in 2012-2014.</td></tr>
<tr><td colspan="6">3. Overall annual adoption of Early and Dry Sowing for wheat by Australian growers in the period of FY 2014-2015 to FY 2019-2020 (in% of overall wheat area sown early and dry).</td><td rowspan="4"></td></tr>
<tr><td colspan="6">Ex-Post Analysis
(The analysis assumes an increment of 1%/ year of overall wheat area sown early and dry in the Ex-post period)</td></tr>
<tr><td>Year</td><td>FY 2014/2015</td><td>FY 2015/2016</td><td>FY 2016/2017</td><td>FY 2017/2018</td><td>FY 2018/2019</td></tr>
<tr><td>Adoption Rate (Overall)</td><td>1%</td><td>2%</td><td>3%</td><td>4%</td><td>5%</td></tr>
<tr><td colspan="6">4. Overall annual adoption of Early and Dry Sowing for wheat by Australian growers in the period of FY 2019-2020 to FY 2024-2025 (in% of overall wheat area sown early and dry)</td><td rowspan="4">5%</td><td rowspan="4">With global climate change expecting to exacerbate and accelerate the occurrence of drought, the key stakeholders in the ecosystem foresee the adoption rate as 10 - 15% in this period.

Analysis based upon an estimate of 5% (assumed constant i.e. no increment for FY 2019/2020 to FY 2023/2024) to support conservative analysis.</td></tr>
<tr><td colspan="6">Ex-Ante Analysis
(The analysis assumes a flat adoption rate of 5% of overall wheat area sown early and dry/ year in the Ex-ante period)</td></tr>
<tr><td>Year</td><td>FY 2019/2020</td><td>FY 2020/2021</td><td>FY 2021/2022</td><td>FY 2022/2023</td><td>FY 2023/2024</td></tr>
<tr><td>Adoption Rate (Overall)</td><td>5%</td><td>5%</td><td>5%</td><td>5%</td><td>5%</td></tr>
<tr><td colspan="6">5. Yield advantage with adoption of Early and Dry sowing and usage of new cultivars (t/ha)</td><td>0.7</td><td>Field trials, simulations, yield prophet data and farmer interviews suggest yield advantage as 0.7-1.2 t/ha. The lower end of the range chosen to support conservative assessment. See Table 8 above</td></tr>
<tr><td colspan="6">6. Yield advantage attributed to adoption of Early and Dry sowing ONLY (t/ha)</td><td>0.35</td><td>Industry experts estimate overall yield gain equally attributable to the adoption of Early and Dry sowing and usage of new cultivars</td></tr>
<tr><td colspan="4">Estimates Validated by: Ron Osmond, GRDC
Comments: Suggested benefits might be too low.</td><td colspan="4">Estimates Validated by: Ross Kingwell, AEGIC Estimates Validated by: Ross Kingwell, AEGIC
Comments: #2, 3, 5 Annual Adoption and yield advantage estimates might be too conservative</td></tr>
</table>

6.1.5 Cost Benefit Analysis Results

The following section presents the results of the CBA, comparing the performance of options using the two-key metrics:

- BCR: The ratio of the present value (PV) of economic benefits to PV of economic costs over the evaluation period
- NPV: The PV of economic benefits delivered by the Early and Dry Sowing work less the PV of economic costs incurred;

The CBA measures the benefit to Australia through this work. To keep the analysis conservative, this assessment accounts deadweight loss of government taxation.
The results of the CBA are summarised in Table 11 and based on costs and benefit items using a real discount rate of 7%. The results are based on data and methodology outlined in Section 6.1.1 -6.1.4.

Benefits FY2014/2015 to FY 2023/2024

Table 11: Cost Benefit Analysis Results (See Table 10 for approach)

Parameter Description	Benefits Estimated		Reference
Inputs for assessment of benefits through the adoption of Early and Dry Sowing program (any year)	Total Area under wheat production (million hectares) in Australia	12	See Table 10 above (1)
	Adoption estimates (overall (in% of overall wheat area sown early and dry)) of Early and Dry Sowing for wheat by Australian growers in FY (of interest)	See Table 10 above (3) and (4)	
	Yield advantage attributed to the adoption of Early and Dry sowing ONLY (t/ha)	0.35	See Table 10 above (5)
	Price / ton of wheat ($AUD/t)	244 (See Appendix A; avg of 2014-2019 used for all years i.e. ex-post as well as ex-ante)	
	CSIRO's attribution	10%	See Table 6 above
Ex-Post benefits associated with adoption of Early and Dry Sowing - FY 2014/2015- FY2018/2019 (overall for Australia, in 2019-2020 $$; ex-post)	180,660,688		$\sum_{n=FY2014/2015}^{FY2018/2019}$ (Wheat Area*Adoption rate*0.35*Wheat price)
Ex-ante benefits associated with adoption of Early and Dry Sowing - FY 2019-2020 to FY 2023-2024 (overall for Australia, in 2019-2020 $$; ex-ante)	224,651,296		$\sum_{n=FY2019/2020}^{FY2023/2024}$ (Wheat Area*Adoption rate*0.35*Wheat price)
Total Benefits (overall for Australia, in 2019-2020 $$)	405,311,984		Ex-post + Ex-ante benefits
Total benefits attributed to CSIRO's work - FY2014/2015 to FY 2023/2024 (based on 10% attribution for analysis period; in 2019-2020 $$)	40,311,98		(Ex-post + Ex-ante benefits)*0.1
Total CSIRO Costs without Deadweight loss (See Table 3)	3,670,572		Table 3
Total CSIRO Costs with Deadweight loss (See Table 3)	4,404,686		Table 3

BCR without Deadweight loss	11:1
BCR with Deadweight loss	9.2:1
NPV without Deadweight loss (in mil $$, 2019-2020 $$)	36.9
NPV with Deadweight loss (in mil $$, 2019-2020 $$)	36.1

The BCR for CSIRO's role in this work varies from 9.2-11 (with or without deadweight loss).

The NPV for CSIRO's role in this work varies from 36.1 – 36.9 (in mil $$; with or without deadweight loss)

In light of the underlying assumptions, the estimated potential benefits delivered by the Early and Dry Sowing research program are expected to exceed the total costs of the research, from the perspectives of the program as a whole.

6.1.6 Externalities, spillovers and economic flow-on effect on non-users

Early and Dry sowing work has generated insights and new knowledge for breeding and agro-chemical companies to help with shaping their research activities and for informed decision making. For e.g. CSIRO researchers are testing long-coleoptile wheat varieties for their ability to enable establishment from deep sowing. Long-coleoptile wheat varieties can be sown deeper into moisture increasing early sowing opportunities and therefore improving the yield benefit through the application of these interventions.

7 Sensitivity Analysis

The CBA is necessarily based on a series of assumptions that mean that there is a degree of uncertainty around the results. Sensitivity testing has been undertaken to clarify which assumption can materially change the results. Sensitivity analysis has been undertaken on the key parameters that include:

• Discount rate: Analysis in Section 6 is based on the real discount rate of 7%. Sensitivity test results are provided for real discount rates of 4% (lower) and 10% (higher)

• Changes in adoption rate: As mentioned earlier, with the global climate change the scientific community foresees greater adoption of this work by the Australian wheat growers in the coming years. To keep the analysis conservative, Section 6 provides the overall adoption during the Ex-ante period (FY 2019-2020 to FY 2023-2024) at 5% (assumed constant). The sensitivity analysis highlights the variation of overall benefits with an assumption of incremental increase of 1%/ annum over ex-ante period of FY2019/2020 to FY2023/2024.

• Changes in CSIRO's attribution ratio: As stated earlier, the benefits generated from this work are a result of efforts from a number of key players in the ecosystem. The analysis in Section 6 is based upon CSIRO's attribution of 10%. Sensitivity test results are provided for 5% (lower) and 15% (higher).

The results of the sensitivity analysis are provided in Table 12.

Table 12: Sensitivity Test results

Variable	BCR		NPV	
	Without deadweight loss	With deadweight loss	Without deadweight loss	With deadweight loss
Real Discount Rate				
No change (7%)	11:1	9.2:1	36.9	36.2
4%	12.6:1	10.5:1	37.5	36.8
10%	9.7:1	8.1:1	36.5	35.7
Adoption Rate (Ex-post, in% of overall wheat area sown early and dry)				
No Change (5% in the ex-ante period)	11:1	9.2:1	36.9	36.2
Incremental increase of 1% / year over ex-ante period of FY2019/2020 to FY2023/2024	14.6:1	12.2:1	50	49.2
CSIRO's Attribution				
No change (10%)	11:1	9.2:1	36.9	36.2
5%	5.5:1	4.6:1	16.6	15.9
15%	16.6:1	13.8:1	57.2	56.5

It is important to note that overall benefits of any research work depend crucially on the adoption profile and actual achievement of the economic, social and environmental benefits. The current assessment lacks benchmark data, there is no organization measuring the adoption profile for the ex-post period and the ex-ante analysis is heavily based on assumptions. Consequently, there is considerable variability in the reported results for the BCRs due to the wide range of assumed input values employed in the model as well as the lack of reliable historical data.

8 Limitations

Limitations

1. This evaluation uses a mixed methodology to evaluate the research impact arising from the Early and Dry Sowing work. It combines quantitative and qualitative methods to illustrate the nature of the economic, environmental, and social impacts of this work. In cases where the impacts can be assessed in monetary terms, a CBA is used as a primary tool for evaluation. As a methodology for impact assessment, CBA relies on the use of assumptions and judgments made by the authors in conjunction with the research team. This relates primarily to the economic indicators for impact contribution, attribution, and the counterfactual. These limitations should be considered when interpreting the results presented in this case study.
2. The author makes significantly conservative estimates for this analysis and this may substantially underestimate benefits generated by CSIRO's contributions. Due to the high magnitude of variation produced by even a small variation in adoption or attribution rates (see Table 12) which is further intensified by the absence of reliable underpinning data and likelihood of other unaccounted factors (some of which could be significant); the analysis was consciously kept conservative. The main intent of this analysis is to demonstrate the growing significance of this work especially with the uncertainties posed by climate change and provide a snapshot of the potential of the return generated from the investment for accountability, communication, engagement, continuous improvement and future application purposes.
3. Given the scope and budget for the analysis, we acknowledge that there are some limitations with regards to the evidence base of impacts.
4. There was no data actively collected at the start or post the project with the view of performing an impact assessment. Any data collection has only been conducted during the course of active projects. Since the benefits are assessed over a maximum of 5-year period post completion of projects, in the absence of any supporting data, a robust analysis was difficult.
5. The program covered in this case-study addresses a systems challenge. The work is not producing a tangible product or technology for which we can measure commercial adoption. Instead, it is producing knowledge for improved practices in a focused and coordinated way. In addition, the project work has been shared with multiple industry partners and a part of the shift is organic change in the ecosystem. So quantifying impact is based upon a number of assumptions. Also, with many key players and multi-phase nature of the work, accurate assessment of CSIRO's attribution has been a challenge.
6. Surveys are often seen as a way to monitor impact. However, farmers often suffer survey fatigue and therefore the results are biased to the opinions of those farmers who respond.
7. A method to detect sowing time using remote sensing vegetation indices was evaluated, but it was found that lack of frequent satellite images during green-up periods restricted the usefulness and accuracy of the approach.

9 Confidence Rating

Data that measures the uptake and adoption of Early and Dry sowing is unavailable thereby making the analysis heavily based upon assumptions. To address this, a) the benefits assessment has been kept conservative and b) the analysis and underlying assumptions have been reviewed and validated by key organizations working in this space as well as customers adopting the new interventions.

The author determines the confidence rating of this assessment as low-medium. Implementation of Recommendations outlined in Section 8 above, is expected to help with a more robust analysis for future assessments.

Appendix A) Wheat Prices – Historical and Future

Wheat prices https://www.macrotrends.net/2534/wheat-prices-historical-chart-data

Aud/USD https://www.macrotrends.net/2551/australian-us-dollar-exchange-rate-historical-chart

Year	USD/ bushel	USD/ ton	AUD/ USD data	AUD/ ton
2014	5.895	217	0.82	264
2015	4.7	173	0.73	237
2016	4.08	150	0.72	208
2017	4.27	157	0.78	201
2018	5.03	185	0.7	264
2019	5.42	199	0.69	289
				Avg of 6 years in AUD/ ton Wheat : 244

This avg price of wheat from period FY2014-FY2019 is used for all years i.e. ex-post as well as ex-ante

Note: Since a price index to enable adjustment of US or international prices is not available for FY2014-FY2019, we have used the six-year average price of $244 AUD for all years in the analysis. No price index was available for wheat quoted in $US, so the six-year average price that has been used for the cost-benefit analysis has been treated as equivalent to working in real prices.

Appendix B) Key factors driving Early and Dry Sowing practices[18]

Uncertainties				
Cropping break date	Time to flowering	Probability and timing of frost	Aggregate Rainfall – April to Aug (incl – to flowering)	Rainfall, winds and temperature at the finish of growing season
Logistical considerations				
Effective work rate of the seeder	Effective hours/day seeding can be scheduled and maintained	Interruptions to the seeding process	availability of and willingness to use contractors	Burden of weed
Other Factors				
Yield response	Extent of effective weed control	Prior soil moisture in the area dry seeded	survival of prematurely germinated wheat seed	Season's rainfall, for at least part of the growing season

[18] Decisions under uncertainty: Seeding wheat before the break. **David M Gray,** Department of Agriculture & Food WA, Katanning

Appendix C) Mechanism of deriving gains through application of Early and Dry Sowing practices

Farmers are deriving yield and profitability gains by using early and dry sowing in a number of ways as listed below:

1. By sowing earlier with appropriate cultivars, farmers are gaining extra yield due to the longer duration of crop growth.
2. At the whole farm level farmers are beginning their crop sowing programs earlier which means that the last paddocks sown are not suffering a yield penalty from being sown late. Normally, the last paddocks sown on a farm have a yield penalty.
3. Farmers that begin sowing earlier are also obtaining profitability gains by being able to sow large farms with less investment in machinery capacity. Thus, farmers are able to make labour efficiency gains via economies of scale.
4. As rainfall declines and the break-of-season becomes less reliable farmers that take early sowing opportunities are able to establish crops at the optimal time.
5. Due to early sowing farmers are also able to manage the frost risk and have more time to grow the rotation crops, thereby lowering the overall risks and increasing profitability gains.