COGGO Council of Grain Grower Organisations Limited ACN 091 122 039	**Final Report** **COGGO Research Fund for projects finishing at the end of 2015** **A project completion report covering the project. The acceptance of a satisfactory report against the objectives of the project, and agreement on the sharing of any commercial returns and/or IP will trigger payment within 4 weeks, by COGGO for any outstanding payments.**

This Final Report should be completed with reference to the Research and Intellectual Property Agreement (the Research Agreement) signed between the proponent and COGGO Pty Ltd.

1. Project information

Project title	**Frost management options to increase wheat grain quality & yield & how these strategies impact on soil erosion along the south coast of Western Australia.**
Commencement Date	1st January 2015
Completion Date	1st June 2016

Name of Proponent	Fitzgerald Biosphere Group (FBG)
ACN/Legal Name or ABN	25 379 271 481
Mailing Address	PO Box 49 Jerramungup WA 6337

Administrative Contact	Natasha Brown
Position	FBG Finance Officer
Telephone	(08) 98 351 127
Fax	(08) 98 351 329
Email	natasha@fbg.org.au

Project Supervisor/Principal Researcher	Sally Major
Position	FBG Research Officer
Telephone	0427 561 209
Fax	(08) 98 351 329
Email	sally@fbg.org.au

COGGO Use Only

Project Number	
Date Received	

## 2. Project results	This section provides a final report against the Project Aim and the Planned Outputs for the Project.

Achievement of the Project Aim	Brief statement of achievement in relation to the aim of the project

The primary aim of the project was to evaluate frost prevention methods, produce a site specific frost management strategy and provide localised information on frost management for farmers in the Jerramungup Shire.

Throughout the project, evaluation on retaining, removing and partially removing stubble was completed regarding frost management and grain yield. Results of the evaluation are discussed in subsequent sections of this report. The impact of each of these strategies on soil structure and erosion was identified through photo monitoring and found to be negligible. Discussion of soil erosion observations is also included in subsequent sections.

From the evaluations, a site-specific frost management strategy has been developed for the grower (Shane Edmonds) and results of the trial have been made available to all local growers through presentations and publications.

The trial was originally planned to take place at Lawson Grains' property at Jacup, however due to crop rotations a suitable site could not be found. Further investigation into potential sites in the Jacup area found no sites suitable for use in 2015 (mostly due to crop rotations). Consequently, the trial was relocated to Needilup where an ideal site was found at Shane Edmond's property. As such, all project aims, outcomes and outputs relating to Lawson Grains/Jacup have been replaced with Shane Edmonds/Needilup.

Project Outputs	Please provide a report on the achievement, or otherwise, of the project outputs as per the planned outputs provided in the Project Proposal.

1	-	Output 1 (from Project proposal) Actual information in the Fitzgerald/Jacup area on the number of frost events we get that affect the yield and grain quality

As per the project proposal, a weather station was installed at the trial site in Needilup. Data from the weather station (available at http://avachat.info/) showed a total of 4 frost events occurred at the site between August and November and ranged from 1 to 6 hours in duration. The table below shows a breakdown of each event.

Date	Hrs below 0°C	Minimum Temp (°C)	Average temp for frost event (°C)
07/09/2015	2	-1	-0.95
20/09/2015-21/09/2015	6 (3 hrs below 0°C then a 2 hr gap above 0°C, then another 3 hrs below 0°C)	-1.7	-1.03
06/10/2015	1	-0.6	-0.6
16/10/2015	3	-1	-0.83

In addition to the weather station, Tiny Tag temperature monitors were installed at 21 locations across the site. The temperature monitors were installed at canopy height (300mm above ground initially and then 600mm above ground later in the season). Data was collected every 15 minutes from 21st August to 13th December. Frost events at canopy level varied greatly from the weather station data and are summarized below.

There were 20 frost events at canopy level at the trial site between August and November, 2015 (Figure 1). The coldest treatment-average canopy temperature recorded was -3.5°C within the retained stubble treatments on the 20th September. Of the 20 recorded frost events, there was

no event that showed significant differences between the three stubble treatments. These results suggest that, in this trial during 2015, the stubble treatments did not alter the severity of the frost. Similarly, statistical analysis of duration at various temperature thresholds within the same frost events showed all treatments performed the same, with no significant difference (Figure 2). This demonstrated that reducing or removing stubble did not influence the duration of the frost event.

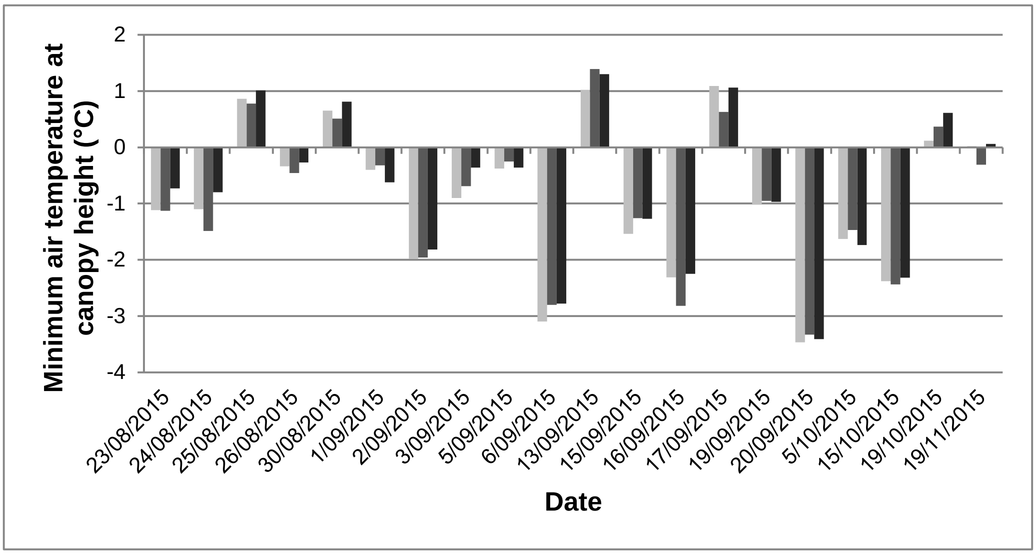


Figure 1 Minimum canopy temperature (un-shielded Tiny Tag TGP-4017) from three treatments, retained (light grey), reduced (dark grey) and removed (black), in Needilup, Western Australia during August–November 2015. No significant differences in minimum canopy temperature were observed.

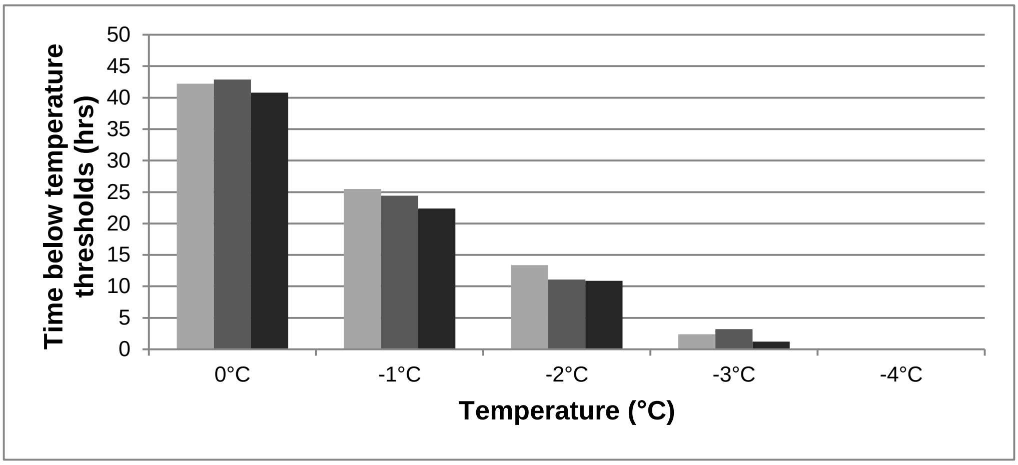


Figure 2 The number of hours experienced from three treatments, retained (light grey), reduced (dark grey) and removed (black) at different canopy temperature during August–November in Needilup, Western Australia in 2015. No significant differences in temperature thresholds were observed.

The difference between the weather station results and Tiny Tag results suggests that there are numerous frost events throughout the season that are likely unrecognized by growers. Additionally, the severity and duration of frost events at canopy level were greater than at a site scale.

2	-	Output 2 (from Project proposal) A frost management strategy that Shane Edmonds can implement
		See attachment ***"Frost management strategy for Shane Edmonds at Needilup, Western Australia"***

3	-	Output 3 (from Project proposal) General Frost management strategies article and a fact sheet that Jerramungup shire farmers can use on their own farms.
		See attachment ***"Frost management in Jerramungup"***

Project results	See attachment "***Frost management options to increase wheat grain quality & yield & how these strategies impact on soil erosion along the south coast of Western Australia: Final Report"*** Results from this trial will be published in the GRDC National Frost Initiative 2014-2015 trials report (Pending. Publication date and title TBC)

This section should cover aspects identified in *Section 7.3* of the Research Agreement

- the results of the Project, including discoveries made and other achievements (including any Project IP and Project Confidential Information);
- the potential application of the outputs of the Project to the Western Australian grains industry and broader community;
- the actual or potential economic benefits flowing to the Western Australian grains industry and broader community from the Project;
- the difficulties encountered;
- the conclusions reached;
- the Researcher's recommendations for any further research;
- a list of scientific papers or publications resulting from the Project; and
- attach copies of any photos, diagrams or other artworks (including, if requested by COGGO, negatives, bromides or the like) which the Researcher has and which may be of assistance to COGGO in the dissemination of information concerning the Project to COGGO's stakeholders.

3. Project resources	This section describes use of the funding listed in the initial plan and any refunds due to COGGO

Expenditure of funds requested from COGGO	$ Total funds budgeted	$ Total funds expended (actual)	$ Total funds requested from COGGO*	$ Total COGGO funds expended	$ Refund due to COGGO of any unexpended COGGO funds
Salary/Contractors	$16,000	$16,000	$16,000	$16,000	$0
Operating costs	$25,400	$25,331.57	$25,400	$25,331.57	$68.43
Capital	$0	$0	$0	$0	$0
TOTAL	**$41,400**	**$41,331.57**	**$41,400**	**$41,331.57**	**$68.43**

*Funding provided by COGGO.

IMPORTANT: Return of unused funds to COGGO is required as per *Clause 3.3* of the Research Agreement.

4. Commercialisation	Insert details of the proposed commercialisation process,as applicable, with reference back to the planned commercialisation plan in the project proposal) for any outputs from the project. This should include recommendations for the commercialisation of the results of the project and the registration or other protection of Project IP and Project Confidential Information as per the Research Agreement.

N/A

It is understood that this may require further discussion and agreement with COGGO via its' agent GIWA, as per the undertakings given and terms agreed, in the project proposal. This can be the subject of an appended letter and attachments. In all cases such discussion and subsequent agreements need to be governed by *Section 8 Project IP, Improvements and Project Confidential information* of the Research Agreement.

5. Communication/ Extension	Insert details of how the communication and extension of the project outcomes has been achieved to date and recommendations for future activities to disseminate and promote adoption of the results of the Project.
Annual Report	A detailed project report will be published in the FBG's 2016 Annual Report, which will be published in December 2016.
Facebook	Advertising for trial update events where discussion and trial results were extended.
Articles	Progress reports on the trial have been published in the FBG's Sustain-a-Bulletin newsletter throughout 2015 and early 2016 and have provided details of the project aims, trial site, progress and results. Additionally, a general fact sheet "*Frost management in Jerramungup"* has been made available to growers through the FBG website and will also be published in the spring Sustain-a-Bulletin, when frost is occuring.
Website	The trial summary, articles and photos are available on the FBG website.
FBG Spring Field Walk (Sept 2015)	A progress report was delivered at the FBG's annual Spring Field Walk, which was attended by 40 people.
Informal field walks	No informal field walks were undertaken to the site in 2015, however numerous one-on-one discussion occurred after FBG events.
Pre-season FBG update "Farm Updates" (Feb 2015 & 2016)	A summary of the project and results were presented at the FBG Farm Updates in Febuary 2016 and published in the Farm Updates handbook, which was available for growers to take home for future reference.
Report to Grower	A localised frost management strategy *"Frost management Strategy for Shane Edmonds at Needilup, Western Australia"* was presented to the trial grower outlining key findings from the project as well as the recommended management strategy.
Nation Frost Initiative Frost Tour	Project Ofiicer, Sally Major, attended the 2015 NFI Frost Tour in WA and represented the trial. Learnings from the tour were applied to the project as well as presented to growers at the Spring Field Walk.
SMS training and development	Project Officer, Sally Major, undertook two days of SMS software training to interpret and analyse yield map data.
Future communication and extension	Grower interest in the frost project was high and as such, FBG sought to continue frost research in the region. FBG's current frost research will continue until 2019, during which time, the results from this trial will be continuously disseminated to growers through several of the above channels including the Spring Field Walk, Farm updates and the website.

Note: As per *Clause 7.3 (b) (ii)* of the Research Agreement COGGO may require the Researcher to produce an edition of the Final Report in a form suitable for general distribution. If so required by COGGO, the Researcher must produce a non-confidential version of the Final Report within 28 days of receiving a request to that effect from COGGO.

## 6. Certification	

The Project Supervisor and the Research Organisation certify that all information contained in, and forming part of, this final project report is complete and accurate. The project supervisor and research organisation further warrant that the project complied with all the relevant guidelines affecting the conduct of research, for example in relation to ethics, bio-safety, environmental legislation, GMAC or National Health and Medical Research Council Codes.

Project Supervisor's signature

Name (in Capitals)

SALLY MAJOR Date: 08/06/2016

Research Organisation signature

Name and title of authorised signatory (in Capitals)

NATASHA BROWN

FBG FINANCE OFFICER Date: 08/06/2016

Completed Final Project reports

Email to coggoresearchfund@giwa.org.au or mail to
COGGO Research Fund, GIWA, PO Box 1081, Bentley DC, WA 6983

For any further enquiries please email questions to coggoresearchfund@giwa.org.au

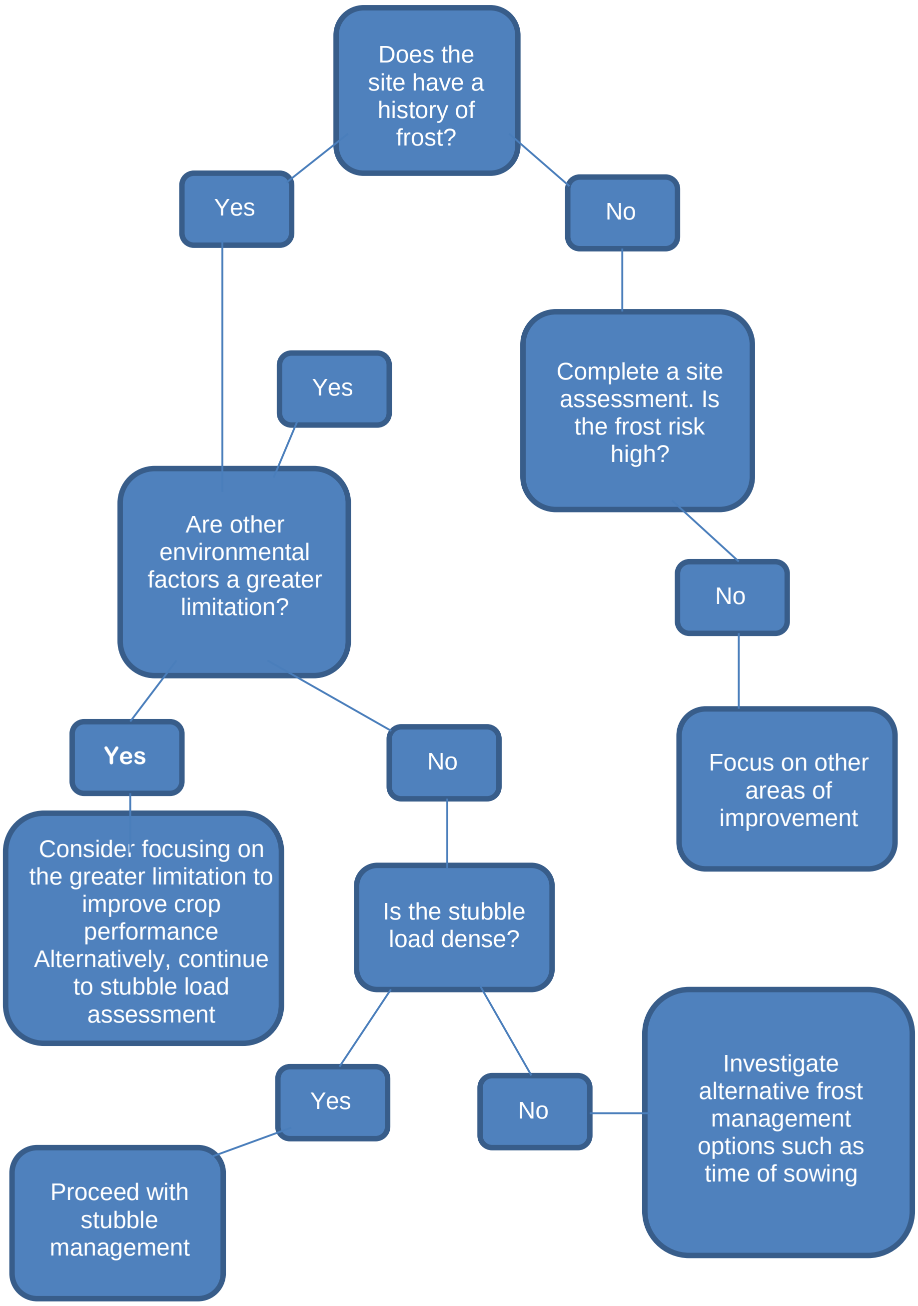
Or phone (08) 6262 2128

COGGO representative

For the purpose of this Project agreement contract, COGGO will be represented by Grains Industry Association of Western Australia (GIWA), or such other representative that is nominated by COGGO as authorised to operate on behalf of COGGO.

Frost management strategy for Shane Edmonds at Needilup, Western Australia

The following strategy has be designed to assist in the management and mitigation of frost at Shane Edmonds's property "Jalna" at Needilup, Western Australia. It has been developed in accordance with results from the FBG's 2015 frost trial, *Frost management options to increase wheat grain quality and yield & how these strategies impact on soil erosion along the south coast of Western Australia,* and is intended only for localised use. The FBG strongly recommends using this Strategy in conjunction with advice from the user's preferred farm consultant. The Strategy is summarised in the figure below.



Determining the best practice approach to manage frost damage and improve crop yield

1. **Frost History**
   Refer to data and observations from previous years and assess how frequent and severe frost events are. If frost history is considered high (i.e. severity or frequency are high), proceed with stubble management analysis. Otherwise, complete a site assessment to determine the potential frost risk
2. **Determine the potential frost risk**
   Complete a site assessment of each paddock (or section of a paddock) to determine the potential frost risk. Frost risk is typically highest in low lying areas with sandy soil. Additionally, sloped sites that are south facing are at a higher risk. If frost history is low and the potential frost risk is low, focus on alternative areas of crop improvement. If potential frost risk is high, continue with stubble management analysis.
3. **Identify environmental limitations**
   Identify other environmental limitations, such as non-wetting soils and consider if they present a larger issue than frost. At Jalna, during the 2015 trial, yield performance was poor despite a minimal percentage of frost induced sterility. This implies that frost may not have been the dominant issue and that poor yields were more likely attributed to other environmental factors such as non-wetting sands (which were prevalent across the site). If environmental factors (such as non-wetting sands) are identified as the limiting factor, consider investing in the mitigation of these issues to provide the greatest improvement in yield. Alternatively, if frost management is still desired, continue with stubble management analysis.
4. **Assess the existing stubble load**
   In the 2015 trial, reducing stubble from 3.88 t/ha to 0.56 t/ha did not result in a significant difference in frost damage of final yield. Complete a stubble biomass assessment (i.e. weigh a given area of stubble to determine the density) to determine if stubble load is great enough to require removal. The threshold for which stubble load impacts on frost is still unknown, therefore this assessment should include further research into other trials and must ultimately depend on the Grower's discretion. If the stubble load is 3.88 t/ha or less, stubble management is not recommended. Alternatively, research and consider other forms of frost management (such as time of sowing). If the stubble load is considered high, proceed with stubble removal as a form of control, ONLY at the Grower's discretion. Due to lack of significant results from the 2015 trial, The FBG cannot recommend stubble management as an effective form of frost management and therefore advises that any stubble removal (even of high stubble loads) is conducted on a trial scale at first to confirm effectiveness.
5. **Stubble management**
   If managing stubble load, postpone removal/reduction until immediately prior to sowing to minimise erosion risk. The 2015 FBG frost trial found no significant difference between removing and reducing stubble on crop benefit. Therefore stubble reduction is the preferred method of stubble management to minimise the soil erosion risk.
6. **Alternative frost management options**
   Regardless of stubble removal, FBG recommends investigating alternative frost mitigation techniques such as managing the flowering window through time of sowing. DAFWA's Flower Power tool enables growers to enter their crop sowing details to calculate the probable time of flowering. The optimal flowering window should be determined based on frost and weather data from previous years, from data sources including (but not limited to) FBG trial results from 2015 and the nearest BOM or DAFWA weather station.

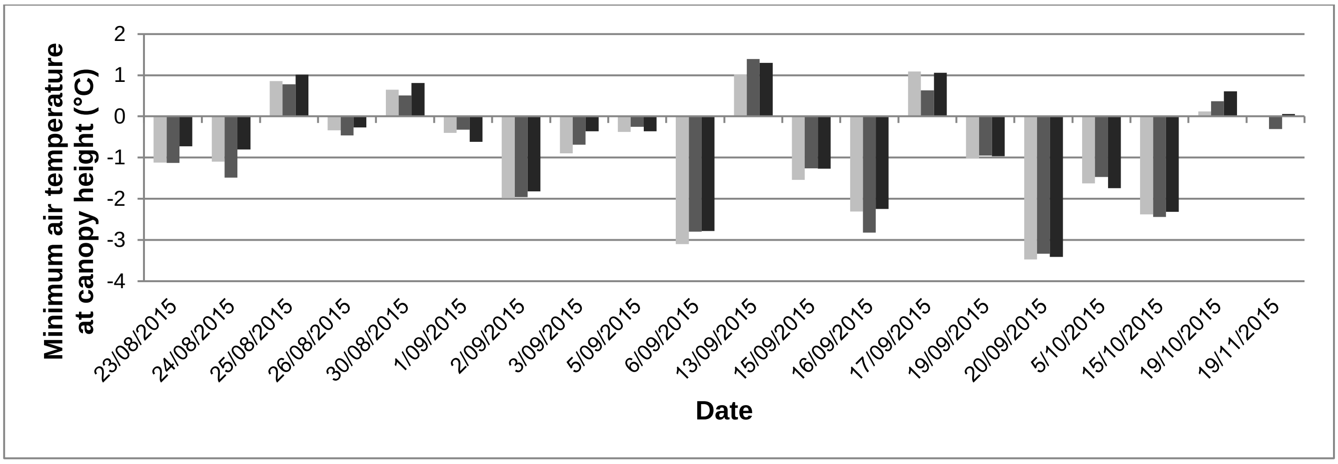
Further information on the FBG's 2015 frost trial and general information on frost management in Jerramungup can be found on the FBG's website www.fbg.org.au

Frost management in Jerramungup

In 2015 FBG conducted a frost trial north of Needilup. The project aimed to assess the suitability of stubble management options for minimising frost damage in cereal crops, with consideration of secondary effects such as soil erosion. Stubble management options included retained stubble (standing stubble with a stubble load of 3.88 t/ha), reduced stubble (raking and burning with a resulting stubble load of 1.59 t/ha) and stubble removal (chaining then raking and burning with a resulting stubble load of 0.56 t/ha) The impact of each treatment was measured extensively to identify any benefits of stubble management of frost mitigation.

Key Frost Observations

- The site experienced 20 frost events at canopy level (temperature dropped below 0°C) between August and November. The severest event reached -3.5°C in a retained stubble during September. Of the 20 recorded frost events, there was no event that showed significant differences between the three stubble treatments for either severity or duration.
- Photo monitoring showed no negative impact of stubble removal on soil erosion. This is considered to be an anomaly caused by the mild climate experienced in the early stages of crop development. Additionally, stubble removal was held off until immediately prior to seeding to minimise wind erosion.
- Frost Induced Sterility (FIS) varied from 5% to 14% across the site and no significant difference was found between stubble treatments. Previous studies suggest that the lack of significant variation is due to the small difference in stubble loads. Although stubble in the retained stubble treatment was 3.88t/ha, results suggest it may not have been high enough in comparison to the other two treatments (1.59 t/ha and 0.56 t/ha). This did not produce large enough temperature variations and discriminating FIS differences. Further assessment of FIS across the slope of the trial identified an average FIS of 8.4%, 8.3% and 8.7% at low, medium and high elevations respectively. This suggests no difference occurred due to slope or treatment.
- All stubble treatments exhibited similar harvest index components, suggesting minimal difference in frost damage which corresponds with the other data collected. Statistical analysis found no difference between treatments for viable heads, non-viable heads, kernel weight, grains per spike, harvest index, maturity biomass, hectolitre dry weight, screenings or grain yield.
- Yields were low across the site and statistical analysis of the yield map data showed no differences between stubble treatments. This is expected as there were no temperature or FIS differences between the treatments.



Indications for Jerramungup growers

- No benefit (regarding frost management) was observed by removing or reducing a stubble load of 3.88 t/ha (approximately 2 t/ha wheat yield)
- It is possible the results were insignificant due to the size of the initial stubble load and therefore, significant results could be found if the initial stubble load was higher (i.e. a high yielding crop).
- Whilst previous research has suggested a benefit from stubble removal, cereal growers in the Jerramungup region are advised to investigate further before implementing stubble management programs for the mitigation of frost.

Frost management options to increase wheat grain quality & yield & how these strategies impact on soil erosion along the south coast of Western Australia: Final Report

Summary

Precision Agriculture (PA) large scale field trials were conducted in a wheat paddock at Needilup, Western Australia in 2015. The trial examined the effects of stubble retention on frost severity and duration. It consisted of Mace wheat planted into either retained (standing stubble with a stubble load of 3.88 t/ha), reduced (raked stubble with a stubble load of 1,59 t/ha) or removed (chained and raked stubble with a stubble load of 0.56 t/ha), in three replicated PA scale plots. Temperature loggers placed at canopy level in all plots recorded 20 nights of 0°C or below, with the coldest treatment-average temperature of -3.5°C. Statistical analysis using ANOVA found no occasions where the stubble treatments influenced the severity or duration of frost events at any point in the landscape. Additionally, there was no significant difference between treatments for frost induced sterility (FIS) which ranged from 5% to 14% and had an average of 11.9%, 7.3% and 6.2% for retained, reduced and removed stubble treatments respectively. Harvest index (HI) assessments for viable heads, non-viable heads, kernel weight, grains, grains per spike, harvest index, maturity biomass, hectolitre dry weight, screenings or grain yield all produced no difference between treatments. Furthermore, yield mapping data showed no difference in crop yield between the treatments. Photographic monitoring of erosion found no difference between stubble treatments, however the mild climate experienced throughout the season limited wind erosion and may have dampened the difference between treatments The combined results suggest that there is no benefit from stubble removal or reduction of 2.29 t/ha at this site during seasons similar to 2015.

Aim

The aims of this trial were to outline changes in in-crop temperature from removing, reducing or retaining wheat stubble and to identify which treatment (if any) reduces the severity and duration of frost, with consideration of secondary effects of erosion.

Methods and limitations

The site selected for this trial was identified as being highly susceptible to frost with strong frost history, sandy soil, a southern facing slope and proximity to a low lying creek. Additionally, it was not subject to interference from factors such as salt, rock piles or cross slope.

This trial design comprised two replicates of stubble treatments (removed stubble and reduced stubble) and three replicates of the "farmer practice" or control, the retained stubble treatment. Treatments were applied along a slope in a frost susceptible part of the landscape (Figure 3). The treatments were systematically ordered within the replicates so that identical treatments were not adjoining and applied to precision agriculture (PA) large scale plots approximately 39 metres wide by 200 metres long. Post-trial assessment has determined that systematic ordering of plots limits statistical analysis; therefore future trials should include a randomised grid layout.

Due to burning difficulties, removed stubble was implemented by chaining and raking, then burning the resulting windrows to achieve a stubble load of 0.56 t/ha dry weight. The reduced stubble treatment had an average stubble load of 1.59 t/ha dry weight, which was achieved via raking and burning the resulting windrows. The farmer practice/control was retained stubble as erosion is considered a more significant issue than frost in this region. This treatment had the stubble cut high (approximately 30 cm) during harvest in 2014 and had an average stubble load of 3.88 t/ha dry weight. Stubble biomass was determined by sampling at three positions in the landscape (high, mid and low) and drying overnight at 65°C to determine dry matter yield. Table 1 summarises the three treatments.

Table 1 Treatments and practises used to achieve stubble biomass

Treatment	Practice	Stubble Biomass (at seeding)
Removed	Chained and raked	0.56 t/ha
Reduced	Raked	1.59 t/ha
Retained	Full stubble	3.88 t/ha

Soil tests were taken prior to sowing. Soil samples were taken from the top 10 cm of soil at three locations within each plot; high, mid and low in the landscape, providing a total of six samples per treatment and nine samples for the control.

Temperature loggers (Tiny Tag Plus 2 TGP-4017) were used to collect unshielded air temperatures at the flag leaf height (approximately 600 mm above the soil surface) every 15 minutes between August and November 2015. Tiny Tags were located high, mid and low in the landscape of each plot (Figure 3). Throughout the season, four Tiny Tags (located at high and low points in the landscape) became dislodged and fell to the ground for an unknown period of time. Data from these Tiny Tags could not be used and the omission of them skewed the averaging calculations across the site. As a result, temperature data analysis was conducted only for the temperature data collected from the mid slope. The reduced data consequently resulted in a large difference being required to create a statistically significant difference.

Rep 1	Rep 1	Rep 1	Rep 2	Rep 2	Rep 2
*	*	*	*	*	*
•	•	•	•	•	•
Retained	**Removed**	**Reduced**	**Retained**	**Removed**	**Reduced**
•	•	•	•	•	•
•	•	•	•	•	•
*	*	*	*	*	*

Figure 3 Trial layout of the extensive stubble management trial in Needilup, Western Australia in 2015. Dots (•) indicate placement of temperature loggers and sampling locations, asterisk (*) indicates additional sampling locations.

Zadok score observations on heading date (Z55) and flowering date (Z65), frost induced sterility (FIS) samples, and harvest index (HI) samples were collected from three pseudo replicates surrounding each Tiny Tag location. Establishment counts were conducted at the Tiny Tag locations and the additional sites shown in Figure 3. HI samples were processed for viable heads, 1000 grain weight, maturity biomass and HI (Pietragalla and Pask 2012). FIS was assessed on a sample of 30 heads from each pseudo replicate collected when the plants were at Zadok 71 and was sampled separately and earlier than HI samples to maintain the integrity of the sample. Plot harvester cuts were originally planned but were not undertaken due to very low yields. The entire trial area was subsequently harvested with farmer machinery fitted with yield mapping capabilities, with all plots harvested in a consistent direction and speed to account for data point recording variability.

Additionally, photographs were taken during each site visit to visually monitor erosion.

Crop and Sowing details

The trial was sown using farmer machinery with all treatments receiving the same seed, herbicide and fertilizer regime throughout the trial period. A mandatory fungicide application was made during the season to minimise the presence of stubble borne diseases, otherwise the crop was managed in season using the farmer's equipment and weed management practices. A summary of sowing and crop agronomy details is provided below in

Table 2. Despite a double knockdown, weed germination was very high and placed a large burden on crop development. Furthermore, inadequate communication resulted in the weed burden remaining uncontrolled until a late season chemical application was undertaken in September. As such the weed burden remained high throughout the growing season, and would have impacted on sterility observed in the FIS results and final yields. However, it impacted the trial site uniformly, therefore lessening the interference with treatment comparisons. Photographs of the weed burden are below in

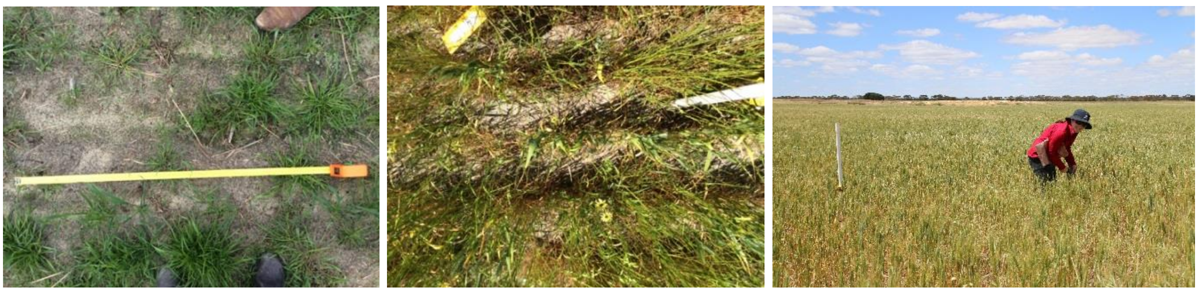


Figure 4 Weed burden across the trial was high (and uniform) across the trial site, despite a double knockdown spray prior to sowing

Table 2 Extensive stubble management trial agronomy information in Needilup, Western Australia 2015.

		Treatment
		ALL (Retained, Removed and Reduced)
Date sown		25/5/2015
Variety		Mace
Seeding rate (kg/ha)		65 kg/ha
Row spacing		254 mm
Nutrition (kg/ha)	**Pre**	90 kg/ha K-Till Extra (CSBP) 50 kg/ha Urea (banded underneath the seed)
	Post	n/a
Herbicide	**Pre**	**KNOCKDOWN 12/05/2015** Glyphosate 1 L/ha Carfentrazone-ethyl (Hammer) 20 ml/ha Oxyfluorfen (Striker) 60ml/ha **DOUBLE KNOCKDOWN 25/05/2015** Paraquat & Diquat (Sprayseed) 1.2 L/ha Trifluralin 2 L/ha Sulfosulfuron (Monza) 25 g/ha
	Post	Triasulfuron (Logran) 10 g/ha (11/09/2015)
Insecticide	**Pre**	Alpha-Cypermethrin 100 ml/ha (25/05/2015)
	Post	Alpha-Cypermethrin 100 ml/ha (11/09/2015)
Fungicide	**Pre**	n/a
	Post	Epoxiconazole (Opus) 300 ml/ha (11/09/2015)

Results and Discussion

Pre-sowing stubble biomass

There was a significant difference of pre-sowing biomass between retained and removed stubble with the removed stubble treatment having significantly lower biomass than retained (Table 4). There was no significant difference between the reduced stubble and either removed or retained stubble. This difference was consistent across the landscape except at the low point where reduced stubble was also significantly lower than retained stubble. This enabled a good comparison between stubble level and stubble management within the trial to try and identify differences.

Soil testing

The site consisted uniformly of sand-sandy loam with no gravel and high conductivity as expected of non-wetting sand. pH (calcium chloride) ranged from 5.0–5.7 which is indicative of moderately acidic soils. Fifty two percent of the site experienced low nitrate nitrogen which is likely due to the high leaching capacity of the sandy soil. The majority of low nitrate nitrogen soils were located at the mid and low points in the landscape. Due to nitrate nitrogen's high solubility and ability to change quickly with mineralisation (Natural Resources South East 2013), the variation across the site was normal and was compensated for by the banding of nitrogen underneath the seed during sowing (refer to

Table 2). Therefore, it is not likely to significantly alter results. Phosphorus levels on high-leaching, sandy soils can be difficult to establish, however concentrations considerably below normal on non-sandy soils can be adequate on sandy soils (Naural Resources South East 2013). Therefore, phosphorus levels at this site typically classified as low were considered to be marginal-adequate for this site and were spatially consistent. Extractable potassium levels were uniformly low across the site and were compensated for in 2015 through the use of CSBP's high potassium fertiliser, K-Till Extra, at sowing. Extractable sulphur and organic carbon levels were consistently high and moderate respectively across the site and were unlikely to affect trial results.

Overall, the effects of variation in soil type were considered to be minimal due to being managed by the farmer throughout the growing season.

Table 3 Pre-sowing soil test results for extensive stubble management trial, in Needilup, Western Australia 2015.

Treatment	Retained									Removed					Reduced						
Landscape	High	High	High	Mid	Mid	Mid	Low	Low	Low	High	High	Mid	Mid	Low	Low	High	High	Mid	Mid	Low	Low
Characteristic/Site																					
Soil texture	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Soil colour	BRGR	GRYW	GRYW	GR	GRWH	GRWH	LTGR	GR	GR	LTGR	GRYW	LTGR	LTGR	LTGR	GR	GR	LTGR	GRWH	GR	LTGR	GR
Gravel %	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pH ($CaCl_2$)	5.0	5.0	5.2	5.5	5.7	5.7	5.2	5.4	5.4	5.3	5.3	5.4	5.2	5.4	5.5	5.3	5.2	5.2	5.0	5.3	5.6
pH (H2O)	5.5	5.5	5.7	6.2	6.2	6.3	5.8	6.0	6.1	5.8	6.0	5.9	6.0	5.9	6.1	5.9	5.8	5.9	5.6	5.9	6.2
Conductivity (dS/m)	0.200	0.070	0.120	0.050	0.130	0.140	0.045	0.238	0.220	0.080	0.096	0.234	0.077	0.200	0.249	0.100	0.140	0.100	0.210	0.280	0.230
Organic carbon (%)	1.02	0.55	1.17	0.90	0.91	0.76	0.64	0.76	0.90	0.92	0.79	0.67	0.80	0.86	0.86	0.96	0.82	0.85	0.93	1.02	0.89
Nitrate Nitrogen (mg/kg)	12	4	5	6	4	4	3	4	5	9	5	5	4	1	4	13	9	2	12	3	3
Ammonium Nitrogen (mg/kg)	6	4	4	1	4	7	4	3	7	3	4	2	4	3	3	2	7	3	4	5	3
Phosphorous (mg/kg)	30	16	17	10	12	13	16	13	14	19	18	17	20	10	11	21	20	9	23	17	11
Potassium (mg/kg)	10	8	18	11	10	17	10	12	14	17	12	12	9	9	15	12	27	10	14	9	11
Sulphur (mg/kg)	55.9	25.6	62.9	13.8	33.6	52.2	20.1	66.7	49.7	21.5	47.0	37.0	27.6	62.3	69.4	24.6	33.5	18.4	49.6	60.1	85.8

Crop establishment and development

Variation in crop establishment between sampling locations was high. Within retained stubble plots plant density ranged from approximately 20–116 plants/m^2. This large variation within the control resulted in large differences being required to achieve a significant difference between treatments. As such, no variation in crop establishment was evident across stubble treatments or slope with the trial site achieving a plant density of approximately 46–76 plants/m^2. The low density of crop establishment was possibly due to a number of factors including low soil temperature, water stress (from non-wetting sand) and weed burden. At the time of germination, the weed burden was observed to range between 48–152 plants/m^2. Later in the season, hot and windy weather caused abrupt development of the crop resulting in plants experiencing multiple stages of development simultaneously. During late heading-early flowering plant development was more advanced in the retained stubble (Table 4), otherwise variation in development between treatments was minimal despite a period of hot, windy weather in late September/early October. This lack of variation is likely due to the non-wetting, sandy nature of the soil inhibiting moisture retention regardless of stubble load.

Observed and measured frost damage symptoms

Assessment of Frost Induced Sterility (FIS) on samples collected from within each treatment along the slope indicated frost damage between 5% and 14%. No significant differences were observed between the stubble treatments (Table 5). Past experience would suggest that the lack of significant variation is due to the small difference in stubble loads. Although stubble in the retained stubble treatment was 3.88t/ha, results suggest it may not have been high enough in comparison to the other two treatments (1.59 t/ha and 0.56 t/ha). This did not produce large enough temperature variations and discriminating FIS differences. Further assessment of FIS across the slope of the trial identified an average FIS of 8.4%, 8.3% and 8.7% at low, medium and high elevations respectively. This suggests no difference occurred due to slope or treatment.

Results from other trial work have shown that FIS has to be in the order of 10–20% to cause any impact on grain yield. As the FIS within this trial was between 5–14% it is expected that minimal yield loss would be identified.

Severity and duration of frost

There were 20 frost events at the trial site between August and November, 2015 (Figure 1). The coldest treatment-average canopy temperature recorded was -3.5°C within the retained stubble treatments on the 20th September. Of the 20 recorded frost events, there was no event that showed significant differences between the three stubble treatments. These results suggest that, in this trial during 2015, the stubble treatments did not alter the severity of the frost. Similarly, statistical analysis of duration at various temperature thresholds within the same frost events showed all treatments performed the same, with no significant difference (Figure 2). This demonstrated that reducing or removing stubble did not influence the duration of the frost event. Further analysis of thermal activity across the slope was unable to be completed due to errors in the temperature data as discussed previously in *Methods and limitations*.

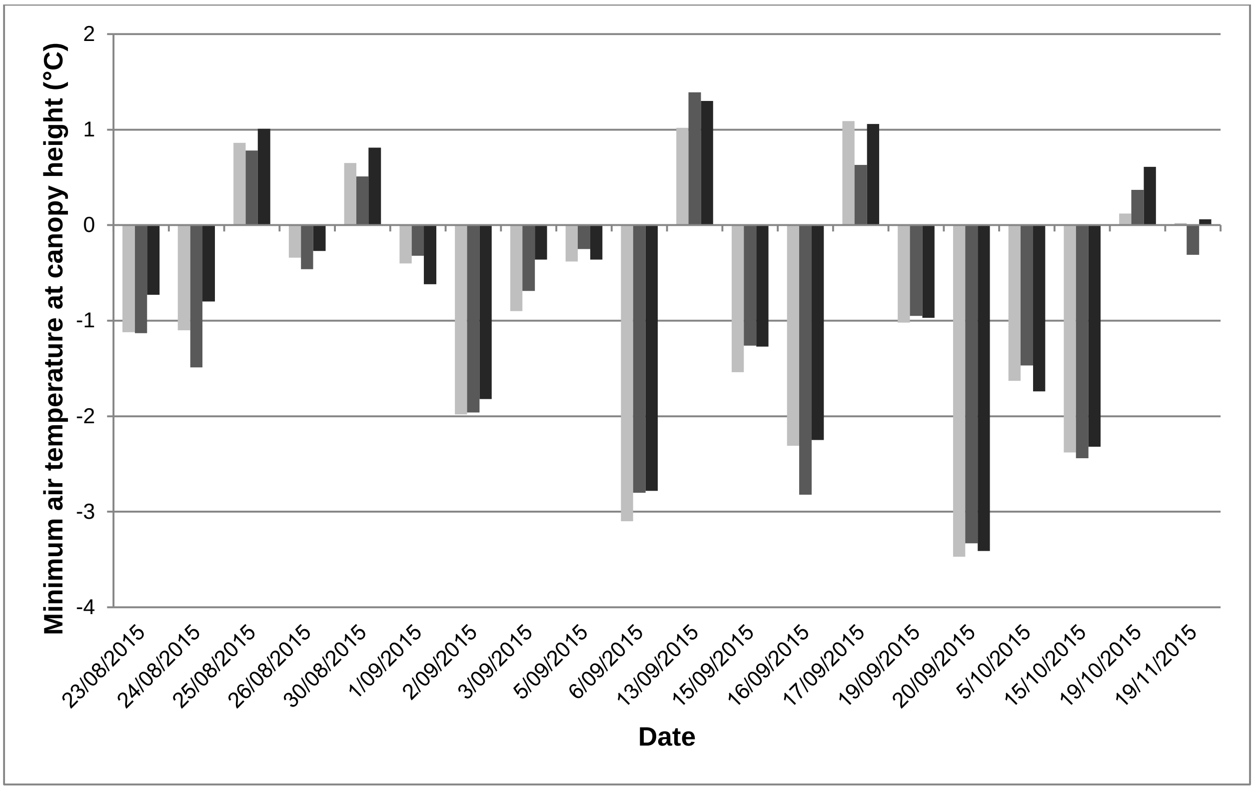


Figure 5 Minimum canopy temperature (un-shielded Tiny Tag TGP-4017) from three treatments, retained (light grey), reduced (dark grey) and removed (black), in Needilup, Western Australia during August–November 2015. No significant differences in minimum canopy temperature were observed.

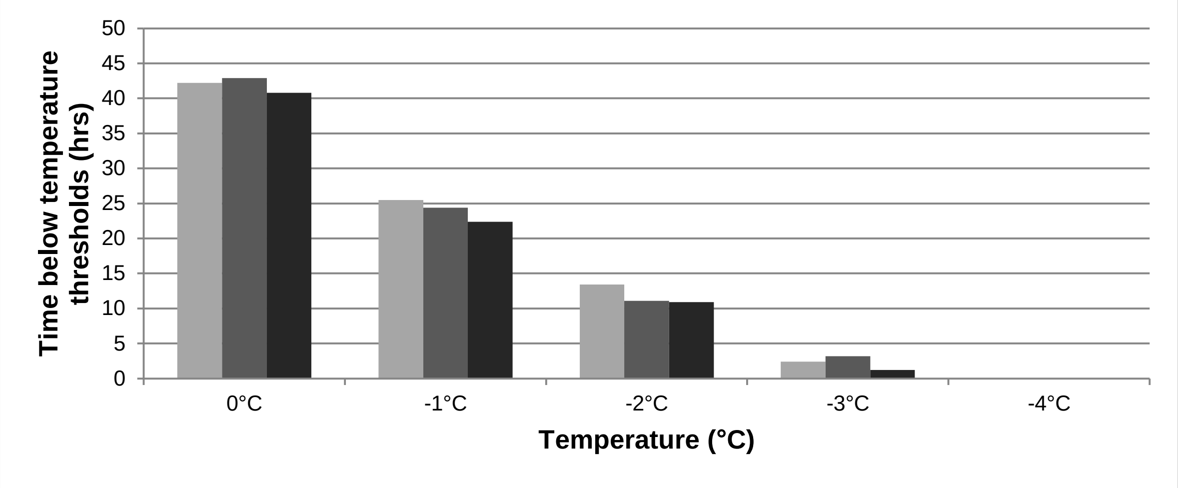


Figure 6 The number of hours experienced from three treatments, retained (light grey), reduced (dark grey) and removed (black) at different canopy temperature during August–November in Needilup, Western Australia in 2015. No significant differences in temperature thresholds were observed.

Yield components and Yield

Harvest yield map data

Yields were low across the site (Figure 7) and statistical analysis of the yield map data showed no differences between stubble treatments (Table 4). This is expected as there were no temperature or FIS differences between the treatments. These results suggest that the grower is able to retain stubble loads of 3.88 t/ha and still achieve the same yield as removing all stubble in a season with similar conditions to those experienced by this trial.

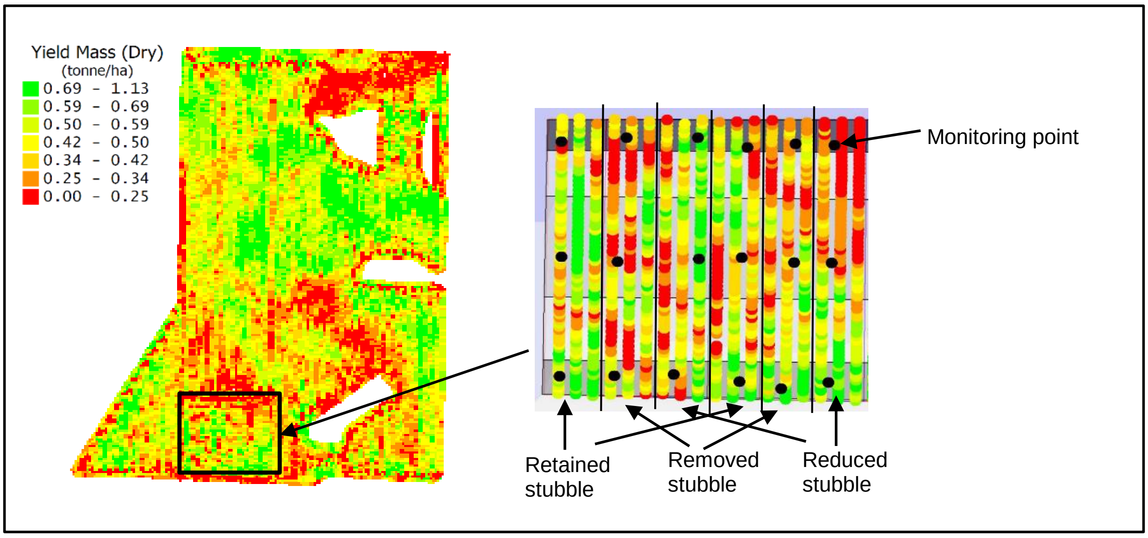


Figure 7 Yield map of trial site in Needilup, Western Australia in 2015. No significant differences in dry yield mass were observed.

Harvest index data

In this trial retained, reduced and removed stubble treatments all exhibited similar harvest index components (Table 5), suggesting minimal difference in frost damage which corresponds with the other data collected above. Statistical analysis found no difference between viable heads, non-viable heads, kernel weight, grains per spike, harvest index, maturity biomass, hectolitre dry weight, screenings or grain yield. This further suggests that the grower is able to retain stubble loads of 3.88t/ha and still achieve the same yield as removing all stubble.

Table 4 Extensive stubble management trial agronomy results in Needilup, Western Australia. Significant differences are indicated by different letters (P< 0.05)

Treatment	Retained	Removed	Reduced	$LSD_{0.05}$
Stubble biomass[1]	3.88	0.56	1.59	2.65
Establishment	70.8	59.2	69.2	95
Zadok Score (24/09/2015)	62.17	61.33	61.5	0.59
Zadok Score (30/09/2015)	64.67	64.33	64.33	1.17
Yield mapping (t/ha)	0.54	0.44	0.45	0.35

1. Stubble biomass at seeding

Table 5 Extensive stubble management trial agronomy Harvest Index results in Needilup, Western Australia. Significant differences are indicated by different letters (P< 0.05)

Treatment	Retained	Removed	Reduced	$LSD_{0.05}$
Viable heads (m^2)[1]	168.4	148.6	150.3	152.11
Non-viable heads (m^2)	5.11	4.44	4.89	6.67
FIS (%)	11.9	6.2	7.3	NA
Kernel weight (mg)	23.49	21.26	20.78	18.69
Grains (m^2)	4801	4204	4120	3870
Grains per spike	28.5	27.8	27.2	6.36
Harvest Index	0.224	0.232	0.241	0.136
Maturity biomass (t/ha)	0.45	0.41	0.4	0.36
Hectolitre harvest index	75.8	72.9	71.8	13.9
Screenings (%) <2mm	26.3	34.2	35.4	57.46
Yield (t/ha) HI	1.18	0.94	0.89	1.7

1. Heads which developed and contained at least 1 grain

Erosion

Throughout the trial, photographic monitoring found erosion was negligible and no substantial difference in erosion was observed between treatments. This result differs from expected as both wind and water erosion are typically an issue in Western Australia. It is suspected that the results were caused by the mild climate experienced in the early stages of crop development. Additionally, stubble removal was held off until immediately prior to seeding to minimise wind erosion. Figure 8 shows the soil surface of a removed stubble plot immediately after stubble removal (before sowing) and during the season.

Figure 8 Erosion on a removed stubble plot from immediately after removal until adequate ground cover was established mid-season. No notable difference was observed between treatments.

Potential practical and economic industry implications

Results from this trial indicate no economic benefit from stubble management of stubbles with a density of 3.88 t/ha or less. This was shown through an absence of yield difference between treatments. Additionally, no benefit was observed regarding stubble management and frost damage. Currently, a lack of conclusive scientific evidence has resulted in growers implementing unjustified practices in an attempt to mitigate the impacts of frost. Stubble management is a well-known practice, which has been increasing in recent years, particularly along the south coast of Western Australia. Results from this trial suggest stubble management is ineffective at reducing frost damage on stubbles with a density of 3.88 t/ha or less and therefore may result in a decline in unnecessary stubble management in these regions. This will lead to a financial benefit growers and will alleviate erosion, which is already a major issue in Western Australia.

Conclusions and recommendations

Results from this trial in 2015 suggest that there is no benefit from reducing stubble loads below 3.88 t/ha on non-wetting, sandy sites in a medium production environment to mitigate against frost damage. Based on the temperature results collected, stubble loads do not alter the severity or duration of the frost and additionally, harvest index and yield data shows that no yield benefit was observed by reducing stubble loads below 3.88t/ha. Therefore, in medium production environments, on non-wetting sands it is not recommended to reduce stubble loads to less than 3.88t/ha to reduce the severity of frosts. However, due to the limitations of this trial, it is advised that further studies are completed in medium production environments to further support the recommendations from this trial. Additionally, further trials in high production environments would support or reject the concept of stubble management to reduce frost damage.

References

Pietragalla J and Pask A 2012. Chapter 18: Grain yield and yield components. In: Pask AJD, Pietragalla J, Mullan DM and Reynold MP (Eds). Physiological Breeding II: A field guide to wheat phenotyping. International Maize and Wheat Improvement Centre, Mexico.

Natural Resources South East 2013. Standard soil test methods & guidelines for interpretation of soil results. Government of South Australia. Available from: www.naturalresources.sa.gov.au/southeast/land/soil-management/Soil-testing-and-observation [15 June 2016].