Stubble load increases frost severity, duration and damage in frost-prone landscapes in south-western Australia

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Abstract
Frost damage across Western Australia's cropping regions causes annual losses estimated to be between \$100 and \$300 million each year. This paper reports on results from field experiments in 2014-2016 investigating whether increasing stubble load influences the severity, duration and damage from spring frost events in wheat crops in WA. In most experiments, increasing stubble load increased the severity and duration of spring frost events. Increased stubble load also increased frost damage and resulted in lower grain yield under moderate and severe frost damage conditions. Reducing stubble load is one tool growers can use as part of a comprehensive frost management plan.

Key Words
Frost, sterility, stubble load, stubble management.

Introduction
Frost damage is a significant challenge for wheat production across Australian cropping regions and the frequency and severity of events is likely to increase under future climate scenarios (Zheng *et al.* 2015; Crimp *et al.* 2016). In Western Australia frost causes annual financial losses in lost yield of between \$100 and \$300 million and similar losses have been recorded in southern and eastern Australia in recent years. Anecdotal and experimental evidence indicate that reducing stubble load could lower frost severity, duration and damage (Jenkinson & Biddulph 2014; Verrel et al 2018). This paper reports on a series of experiments examining the impact of stubble load on frost severity, duration and damage in frost-prone parts of the landscape.

Methods
Experiments were sown into a flat, frost-susceptible part of a paddock with a history of multiple frost events. Local farm management practices were used to establish the trials. A commercial wheat of barley cultivar (Table 1) was sown using local agronomic practices, including crop rotation. Additional prophylactic fungicides were applied at stem elongation and flag leaf emergence to minimise foliar diseases. Stubble residues were applied to the standing wheat crop in 10–15m^2 plots at rates from 0–8t/ha and replicated 3-4 times in a RCB grid design in eight experiments over 2014-2016. Tiny Tag temperature loggers (TGP-4017) were installed within each plot to measure canopy temperature at 600mm every 15 minutes from canopy closure through to senescence. Frost severity and duration were calculated when temperatures fell below sub-zero during the susceptible developmental window of Zadock (Z) 45-85. From Z40 (flag-leaf sheath extending) onward crop development was assessed weekly. At Z85 (late dough), 30 heads were collected from three locations near temperature sensors and assessed for floret sterility (FS) , irrespective of whether frosts had occurred or not. Biomass cuts were collected at Z89 (hard dough) for harvest index, 1000-grain weight, hectolitre weight and screenings. At maturity, two small plot-header samples were taken either side of temperature sensors.

Table 1. Site, location and year of experiments in the WA trial program from 2014-2016.

Experiment	Year	Site	Variety sowing date	Frost intensity
WSR14CUBA6	2014	Cuballing	Yitpi 24th May 2014	Minor
WSR14CUND6	2014	Cunderdin	Hindmarsh 7th May 2014	Minor
WSR14TINC6	2014	Tincurrin	Mace 27th May 2014	Minor
WSR15CUBA6	2015	Cuballing	Magenta 25th May 2015	Severe
WSR15CUND6	2015	Cunderdin	Mace 26th May 2015	Severe
WSR15TINC6	2015	Tincurrin	Mace 26th May 2015	Minor
WSR16CUBA6	2016	Cuballing	Magenta 19th May 2016	Moderate
WSR16YORK6	2016	York	Mace 19th May 2016	Severe

Results and Discussion

Throughout the three years of experiments, six of the eight stubble-rate trials (Table 1) showed that increasing stubble rate increased the severity and duration of frost events (Figure 1). Figure 1 depicts the increase in frost duration measured as hours below 0°, and -2°C and shows a consistent increase in frost severity with higher stubble rates across the six experiments. In the other two experiments, a similar response was observed but this were excluded from the temperature analysis presented in Figure 1 due to limited frosts in WSR14TIN60 and incomplete temperature data between Z40-85 in WSR15CUND6. At the three sites with the greatest frost intensity (Table 1; WSR15CUBA6, WSR16CUBA6 and WSR16YORK6) there was, as expected, a greater duration below the minimum temperature thresholds (Figure 1) and also more time spent at the lower temperature thresholds of -2. Not all experiments reached the lower temperature thresholds of -2 °C (Figure 1b).

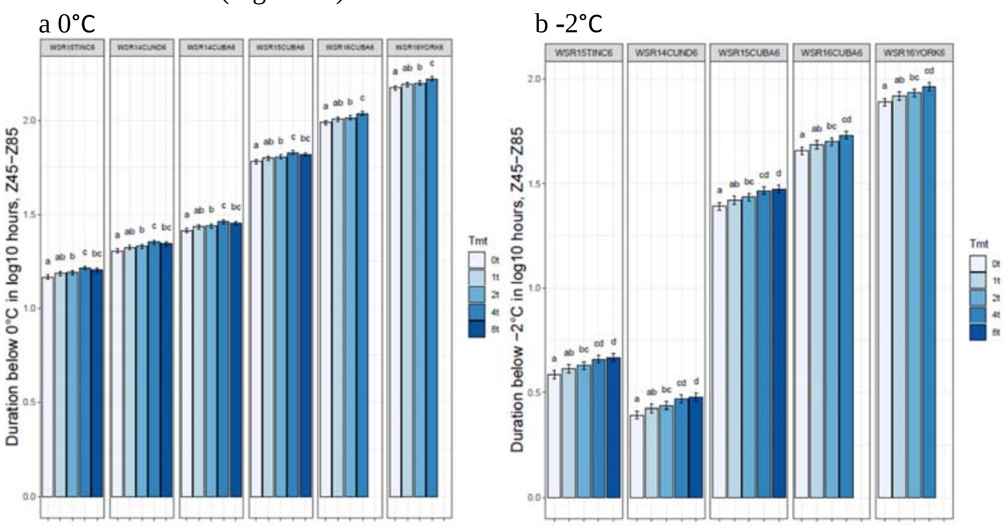

Figure 1. Impact of stubble rate on predicted mean (log 10-trandformed) of the duration in hours below 0°, (a), -1° and (b), -2°C. Experiments were ranked according to magnitude of frost duration. Error bars give +/- 0.5 $LSD_{0.05}$ for comparisons within not between experiments, significant differences indicated by different letters.

Higher frost severity and duration was associated with higher floret sterility (FS) at most trials with frost damage occurring when floret sterility was above 20% (Figure 2a; WSR15CUBA6, WSR16CUBA6 and WSR16YORK6). At these sites the higher stubble treatments were also associated with a reduction in grain yield compared to the control. (Figure 2b). Although all trials experienced frosts, not all experienced enough frosts to cause damage. Further insight is provided by examining the experiments that experienced frost-induced floret sterility > 20%. The most severely frosted experiment was York 2016. In this trial, there were 53 frost events from August to October and on 33 occasions the 4t/ha stubble treatment resulted in significantly lower minimum temperatures compared to the control. Across the 53 frost events, the 4t/ha stubble treatment also increased frost duration such that the plots spent longer at 0, -1, -2 and -3ºC compared to the control (Figure 3b). York 2016 also experienced ten frost events during the flowering window between September 19–29, with -6.2ºC the lowest temperature recorded at the site during this period. On three occasions during this time the 4t/ha stubble treatment resulted in an increased frost severity (lower minimum temperature; Figure 3a) and was also significantly colder than the 0, 1 or 2t/ha stubble treatments (Figure 3a). The lower stubble levels of 1t/ha did not increase the severity and duration of frosts compared to the control (complete stubble removal).

The differences in frost severity and duration were also associated with differences in grain yield. Control plots yielded 0.82t/ha, which was two to three times higher than 2t/ha and 4t/ha stubble treatments at 0.39t/ha and 0.23t/ha (Table 2). The grain yield of all treatments at this site was about 4t/ha lower than the yield potential and FS for all treatments was >96%, demonstrating the severity of the frost damage during the 2016 season. While increasing stubble loads increased frost severity and duration and resulted in lower grain yields, frost damage could not be avoided at this site using stubble management alone. However, the results demonstrate that lowering stubble loads (at this site and season) can reduce frost severity and duration and increase grain yield in even the most frost-prone part of the landscape.

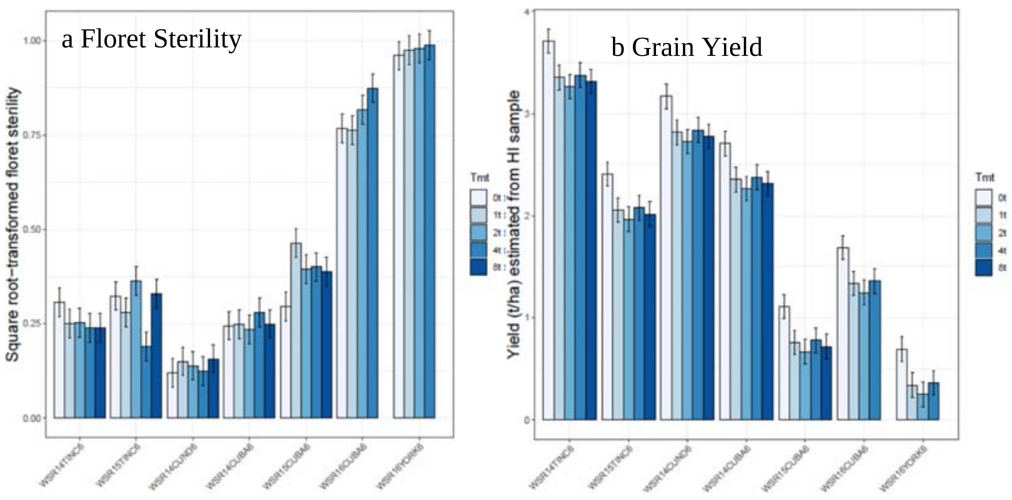

Figure 2: Impact of stubble rate on floret sterility (a; square root transformed) and grain yield (b; t/ha from maturity cut). Experiments are ranked according to magnitude of frost duration. Error bars give +/- 0.5 $LSD_{0.05}$ for comparison within not between experiments.

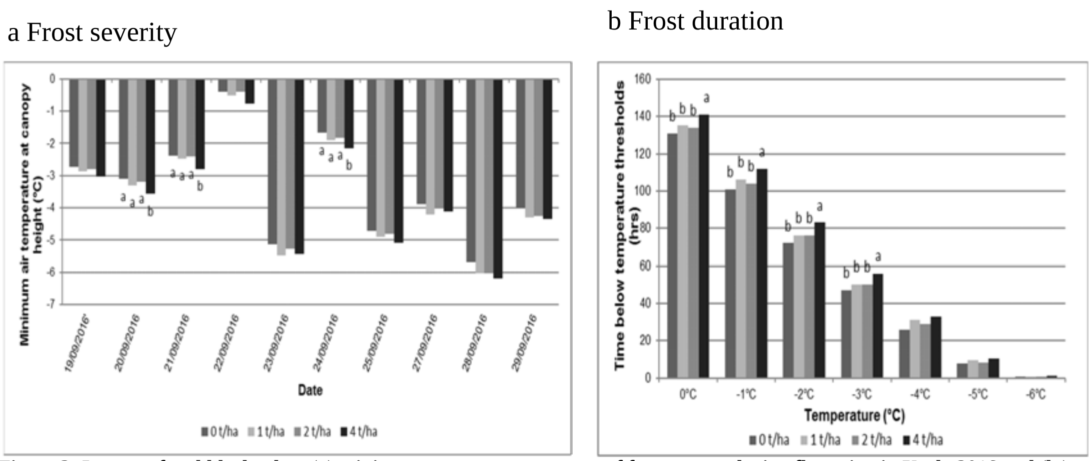

Figure 3: Impact of stubble load on (a) minimum canopy temperature of frost events during flowering in York 2016 and (b) number of hours below different temperature thresholds for frost events between August and October in York 2016. . Significance indicated by letters based on unprotected Fisher LSDs (P<0.05) within each frost event/temperature threshold.

Table 2: Impact of stubble load on grain yield, quality (plot header), biomass and harvest index (HI) of Mace wheat at York in 2016 (WSR16YORK6). Significance indicated by letters based on protected Fishers LSDs (P<0.05)

Stubble rate	0t	1t	2t	4t	$LSD_{0.05}$
Grain yield (t/ha)	0.82a	0.48ab	0.39b	0.23b	0.46
FS (%)	96	97	98	99	3
Maturity biomass (t/ha)	12.9	12.2	13.2	12.1	0.47
HI	0.04b	0.03ab	0.03ab	0.01a	NA
1000 GW	38.3	36.7	38.7	34.4	6.13
Screenings (%) <2mm	1.01a	1.08a	1.18a	1.82b	0.41

In seasons and sites with very severe frosts, higher stubble loads increased frost severity and duration but eliminating stubble completely did not reduce frost damage enough to increase grain yield. As an example, at Cunderdin in 2015, eight frost events occurred during flowering between 30 August and 7 September, with the lowest temperature recorded at -6.2°C (Figure 4a). Stubble rates of 2, 4 and 8t/ha increased the severity and duration of frost events compared to the 0 and 1t/ha stubble treatments (Figure 4a & b). Based on the maturity biomass at this site, grain yield was estimated to have a potential of 2t/ha, however the final yield was between 0.2 and 0.3t/ha. No variation in grain yield was evident between the treatments (Table 3). The FS scores indicated a reducing stubble to 1t/ha lowered sterility compared to all other stubble rates, but sterility across all treatments was very high at >90%. As with the York 2016 trial, increasing stubble loads (in this case above 1.0t/ha), increased the severity and duration of frost events. However, given the severe events and frost damage (>90% FS), reducing stubble could not reduce frost severity and duration enough to increase final grain yield.

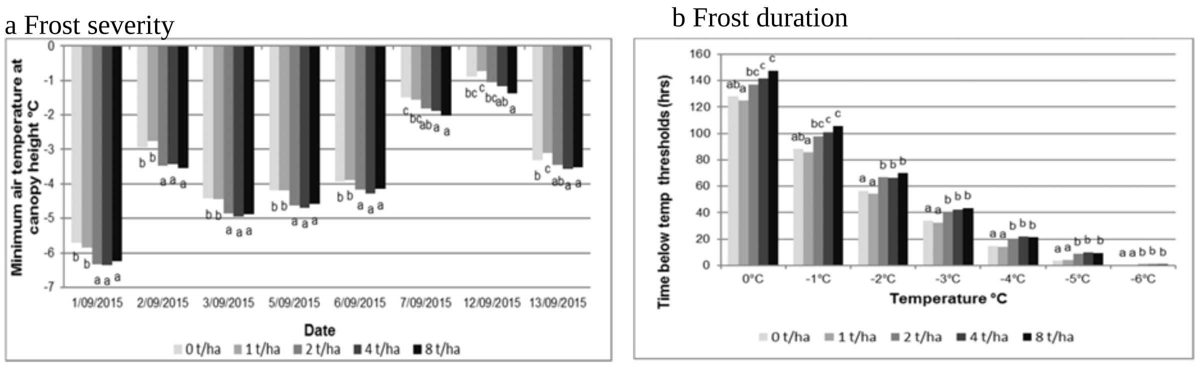

Figure 4: Impact of stubble load on (a) minimum canopy temperature of frost events during flowering in Cunderdin 2015 and (b) number of hours below different temperature thresholds for frost events between August and October . Significance indicated by letters based on unprotected Fisher LSDs (P<0.05) within each frost event/temperature threshold.

Table 3: Impact of stubble load on grain yield and quality (plot header) and biomass and harvest index (HI) of Mace wheat at Cunderdin in 2015 WSR15CUND6). Significance indicated by letters based on protected Fishers LSDs (P<0.05)

Stubble rate	0t	1t	2t	4t	8t	$LSD_{0.05}$
Grain yield (t/ha)	0.30	0.23	0.26	0.26	0.20	0.17
FS (%)	94b	88a	99c	98c	99c	4
Maturity biomass (t/ha)	4.9	5.5	4.7	5.8	5.0	1.1
HI	0.09a	0.10a	0.07ab	0.05b	0.08ab	0.04
1000 GW	28ab	26a	32b	28ab	29ab	5
Screenings (%) <2mm	8.6	11.1	7.4	7.6	6.6	7.3

Conclusion

Experiments over three years indicate that when stubble is applied to standing crops in minor, moderate and severe frost environments, higher stubble loads increase the severity and duration of frost events, resulting in more frost damage and lower grain yield and quality in moderate to severe frost seasons. Managing stubble loads in these environments could be one approach growers could use as part of a comprehensive frost management plan. The benefit of removing stubble appears to outweigh the costs in moderate to severe frost-prone environments. In seasons without frost there was no 'once-off' opportunity cost of stubble removal. Reducing stubble in frost-prone regions, could include cutting low and windrow burning in all seasons as is current practice for integrated weed management. Coupled with a strategic blanket burn, in years with an early break just before Research is ongoing to identify the cause of the increased frost severity, duration and damage under stubble and why yields were also lower in plots sown into cereal stubbles without frost.

Acknowledgements

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