Stem elongation frost damage in cereals in southern NSW

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Abstract
We conducted experiments in 2017 and 2018 to investigate the suitability of growing a number of different varieties of wheat, barley and oat varieties differing in phenology across multiple sowing dates in a frost prone landscape, near Wagga Wagga, New South Wales (NSW). Due to the severity and duration of frost events throughout the 2017 and 2018 growing seasons, stem elongation frost damage was observed in all sowing dates including the varieties with a winter habit. Stem elongation frost damage led to tiller death and delayed flowering for most varieties as many new tillers were produced after the frosts. The early and late May sowing dates (where the start of stem elongation has been delayed) from 2017 were the highest yielding overall followed by the mid and late April sowing dates in 2017 due to the crops exposure to less frost events during stem elongation and well-timed rainfall events late in the season. Barley was higher yielding then wheat and oats in 2018 from all sowing dates, with the oats achieving higher yields than wheat when start of stem elongation had been delayed in the early-May and late-May sowing dates. With an increase in stem frost events in recent seasons in NSW, growers need to be mindful to match variety phenology with sowing date to avoid frost damage during the stem elongation phase.

Key Words
Frost, cereals, sowing time, phenology, stem frost

Introduction
Frost damage in the early stages of stem elongation has been a major constraint for cereal grain production in recent seasons in southern New South Wales (NSW), particularly during 2014, 2017 and 2018. In frost prone areas it is common practice to match phenology with sowing date to ensure flowering begins after the major frost risk period, whilst still aiming to not flower too late to avoid water and heat stress during grain fill. Although heading and flowering are considered the time when plants are most susceptible to frost damage (Frederiks *et al.*, 2015), damage can occur at any time, but more severe conditions are required. Cereal crops are also susceptible to death of the meristem from stem elongation onwards (GS31 growth stage). This is the commencement of the stage where the growing tip is carried above ground level as the stem elongates. Observations from the 2014 season indicated that severe frosts at the stem elongation stage can result in damage to the stem internodes and/or death of the growing point resulting in subsequent death of the main stem and tillers, with grain yield losses observed.
Traditionally, barley and oats are considered more frost tolerant then wheat, however this comparison has most often been made for frosts around anthesis. The different phenological traits, overall plant characteristics and locality of where these species are grown in the landscape often makes it hard to compare between the species.
We conducted mixed species (wheat, barley and oats) sowing date experiments in a frost prone environment near Wagga Wagga NSW in 2017 and 2018 to determine the response of different cereal species to severe frosts especially during early reproductive growth stages.

Methods
For experiments in 2017 and 2018, wheat, barley and oat varieties were assessed across four sowing windows in frost prone landscapes near Wagga Wagga, NSW. The four times of sowing (kept consistent for both years) were: 11 April (mid-April), 20 April (late-April), 4 May (early-May) and 25 May (late-May). .

Table 1: Maturity-type of wheat, barley and oat cultivars used in the sowing date by crop-type trial at Wagga Wagga, NSW in 2017 and 2018

Phenology Type	Wheat	Barley	Oats
Early	Emu Rock^A	La Trobe^A	Durack^A
Mid	Scepter^A		Mitika^A
Mid-long	LRPB Trojan^A	Commander^A	Bannister^A
Long (mild Photoperiod	Cutlass^A		
Long (strong Photoperiod)	LRPB Eaglehawk^A		

Winter	LRPB Kittyhawk^A	Urambie^A

Varieties with reasonable performance across southern Australia production systems were selected to represent the different phenology classes within each crop type (Table 1). Within each sowing window, a restricted randomization approach was used with varieties of three crop types (oats, wheat & barley) randomised to crop type blocks in a randomized lattice. Each sowing window comprises three replicates and each sowing window was considered a separate environment not a treatment per se.

To monitor the differences in crop canopy effects on frost severity and duration, unshielded air temperature was measured at canopy height with Tiny Tag Plus 2 (TGP-4017) loggers with internal temperature probes. Loggers were installed north facing with the internal temperature sensors facing upwards. Temperature was logged every 15 minutes between the start of stem elongation (GS31) and crop maturity (GS87) in a reference variety in each of the three species (wheat – cv. Scepter^A; barley – cv. La Trobe^A; oats – cv. Bannister^A) in all three replicates in each sowing treatment. Temperature sensors were installed when the earliest maturing treatment was at GS31 and increased in height in 100 mm increments fortnightly as the canopy grew to maintain +/- 100mm of the canopy boundary layer/flag leaf height. Loggers were cable tied to a white, 50 mm diameter 1200 mm high polyvinyl chloride pipe in the middle of the plot.
Reference air temperature was measured with a Stevenson screen by a weather station located at the experiment site.

The experiments was monitored to determine key crop development stages and was machine harvested at maturity with edge rows removed.

Results

Seasonal Conditions

The 2017 growing season in southern NSW experienced an above average number of extreme frost events. At the Wagga Wagga site, there were 103 recorded frost events from the unshielded temperature loggers at canopy height, with 87 of these recording temperatures below -2.0°C. The coldest temperature recorded at canopy height was -9.6°C on 1 July (Figure 1). Slightly less severe conditions were observed in 2018 at Wagga Wagga; 101 frost events were recorded with the unshielded temperature loggers at canopy height, with 65 below -2.0°C, the lowest recorded on 28 August at -10.5°C (Figure 1). Screen temperatures on average measured two degrees warmer than those at crop canopy height (Figure 1), emphasising the fact that the canopy experiences colder temperatures than those measured by weather stations as previously reported by Frederiks *et al.* (2012).
Historical weather data (source: Australia CliMate) indicates that the occurrence of frost events are becoming more prevalent, with 9 severe frost events (screen temperatures) below -3°C occurring in the last 5 years through August and September compared to the long term average of 0.5 times per year. Temperatures of below -3°C have occurred in 10 of the last 39 years, with half of these being in the last 10 years.

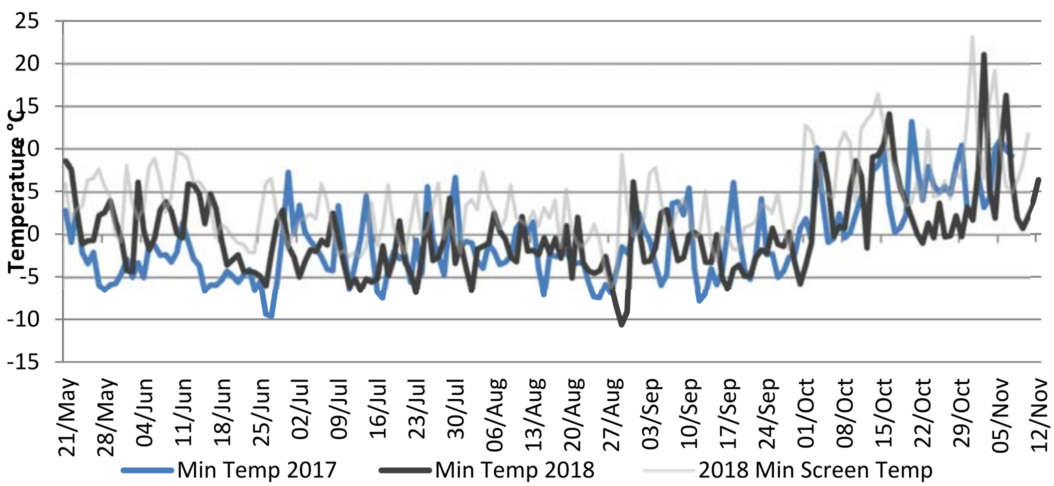

Figure 1: Minimum daily air temperature at canopy boundary layer during 2017 and 2018 growing seasons compared to Stevenson's screen air temperature at Wagga Wagga, NSW.

In 2017, on average, the canopy at Wagga Wagga was exposed to 819 hours below 0°C for the mid-April sowing, 658 hours below 0°C for the late-April sowing, 439 hours for the early-May sowing and 289 hours below 0°C for the late-May sowing. Duration of frost events was shorter in 2018 with the mid-April sown crop exposed to on average 660 hours below 0°C, the late-April sowing 620 hours, the early-May sowing 505 hours and the late-May sowing exposed to 271 hours below 0°C

The growing season rainfall (Apr-Oct) at Wagga Wagga was 199 mm for 2017 and 138mm in 2018, well below the average of 321 mm. There was above average rainfall in 2017 for the month of October, with 64mm at Wagga Wagga.

Phenology

For the first three sowing dates at Wagga Wagga in 2017 (mid-April to early-May), there were 31 to 36 days difference in time from sowing to GS31 between the fast spring types and winter types in both wheat and barley. For example, from the mid-April sowing, Emu Rock^{A} reached GS31 on 12 June, whilst LRPB Kittyhawk^{A} reached GS31 on 13 July in 2017. However, in the later May sowing date, this reduced to only 13 days between the earliest (La Trobe) and the winter wheat LRPB Kittyhawk^{A}. Slighty larger gaps were seen in 2018 with 42 to 54 days difference in GS31 between the fast springs and winter type barleys and wheats in the mid- and late-April sowing dates. The barleys were closer in the early- and late-May sowing dates with 26 to 29 days difference between LaTrobe^{A} and Urambie^{A}. The early-May wheats had 50 days difference between Emu Rock^{A} and LRBP Kittyhawk^{A}, the late-May sowing date having 35 days difference. The number and severity of frosts experienced resulted in all varieties, regardless of phenology type, being exposed to frost during stem elongation. The faster developing varieties were exposed to a greater number of frost events after the start of stem elongation (Figure 2).

Varieties compensated for the stem elongation damage by initiating new tillers. These tillers often contributed to the majority of grain yield, especially from the earlier sowing dates. The process of tiller death from stem elongation frost and subsequent regrowth meant that the time for each plot to reach growth stages beyond GS31 was longer than typical. As affected tillers were dying, their development slowed then ceased. Until tillers showed obvious signs of senescence (yellowing) it was difficult to establish how badly they had been affected by frost without detailed dissections. Consequently, crop growth stage continued to be recorded on affected tillers, resulting in slowing or stagnation of development scores. When later-developing or regrowth tillers caught up to and overtook the dying tillers, scores for crop growth stages increased. This delay and increased spread in apparent phenological development of the crop meant capturing representative heading (GS49) and flowering (GS65) dates proved challenging and were likely misleading. Consequently, those data are not discussed in detail here.

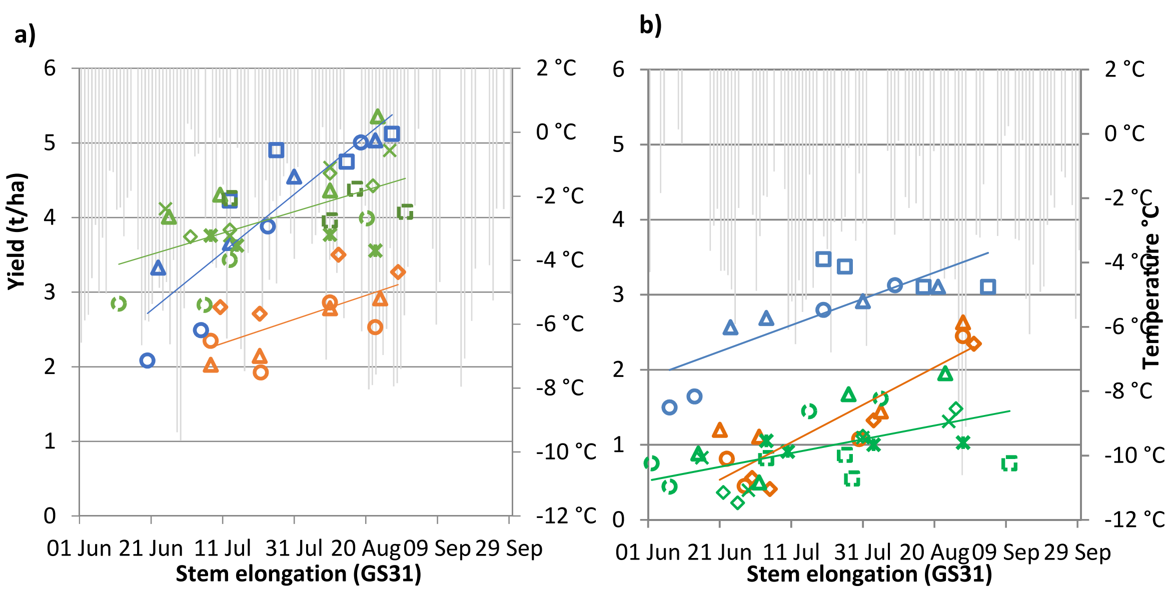

Figure 2: The relationship between timing of the start of stem elongation (GS 31) and grain yield (t/ha) for the three cereal species grown in the experiment at Wagga Wagga in 2017 (a) and 2018 (b). The light grey bars show the occurrence and severity of frost events measured at canopy height with un-shielded Tiny Tag (TGP-4017).

Yield

For all species and in both seasons, grain yield increased as stem elongation was delayed (Figure 2). Oats yielded consistently lower than wheat and barley in all sowing windows at Wagga Wagga in 2017 and were generally penalised from early stem elongation. Wheat performed better than barley when the start of stem elongation was mid-June to mid-July, with barley yielding slightly more than wheat where stem elongation was delayed until late-July. In 2018, barley was consistently higher yielding than wheat and oats from all sowing dates. Oats were comparable to wheat when stem elongation started before August, however yielded on average 1.1t/ha higher than wheat where stem elongation started late-August to early-September. (Figure 2)

Due to the winter varieties requirement for vernalisation (LRPB Kittyhawk^A wheat and Urambie^A barley), stem elongation was delayed. They were able to avoid some of the severe frost events, potentially avoiding stem frost damage which caused them to have a more stable yield for all sowing windows, yielding between 4 t/ha and 5 t/ha in 2017.

Very fast developing varieties such as La Trobe^A barley and Emu Rock^A wheat benefitted from delaying the start of stem elongation, which is when they achieved their highest yields. This is likely as a result of reduced exposure to frost events in this sowing window and then able to mature before severe terminal stress. The slowest maturing oat (Bannister^A) had the highest oat yield at all sowing times. Overall, the trend of increased yield was related to matching sowing date and varietal phenology. Sowing much earlier than recommended (for varieties to flower in the optimum flowering window - early to mid-October for the Wagga Wagga region) was penalised due to stem elongation frost. Sowing slightly later than recommended escaped late heat and drought in 2017 due to the slightly above-average rainfall in October.

Conclusion

In a year such as 2017 and again in 2018 which saw extreme frost events throughout the growing season, all varieties displayed the ability to recover from frost damage at stem elongation to some extent through re-tillering, which did contribute to the yields. For early sowing times, the longer-season winter-type wheat or barley varieties were better suited in frost-prone areas. For late-May sowing times, the shorter-season varieties were more suited. Although it has been common practice to match phenology to sowing date to begin flowering when the frost risk has passed, the higher number of severe frost events that have been occurring has highlighted the need to not only match the flowering time with sowing date but also the start of stem elongation to reduce the risk of stem frost damage in frost prone areas.

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CliMate Weather Data https://climateapp.net.au, accessed 20 June 2018

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