Reduced nitrogen and seeding rates in frost prone landscapes does not reduce frost damage

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Abstract
Reducing nitrogen and seeding rate to half of farmer practice can reduce frost severity and duration but not frost damage. In areas of low frost-risk or in non-frosted crops there is, as expected, a clear financial response to nitrogen. In moderately frosted crops with significant frost damage at stem elongation or pre-heading/booting, there is likely to be either no response or a small, positive response in yield and gross margin to nitrogen application. In crops severely frost damaged at flowering and those frosted later during grain-fill there is not likely to be any loss in gross margin with nitrogen application in line with local agronomic practice and long term yield potential. In frost-prone landscapes, maintaining normal grower practice for seeding rate and nitrogen for local yield potential is likely to give the greatest financial return in years without frost, some financial advantage in years with moderate frost and, importantly, no negative consequences in years with severe frost.

Keywords
Frost, wheat, nitrogen, seeding rate, canopy management, plant density.

Introduction
There is anecdotal evidence from growers, identified through the RCSN networks, that crop canopies with higher yield potential are more susceptible to frost damage. Growers routinely report that nitrogen (N) applied after tillering in years of high yield potential appears to increase frost damage in frost-prone areas. As well as cereals crops growing after legumes in the rotation. Based on trials done in Western Australia (WA) and South Australia (SA), Rebbeck and Knell (2007) recommended conservative N inputs in frost-prone landscapes. As a result, it has been recommended that growers adopt conservative nitrogen strategies in frost prone areas, which may limit yield potential when frost does not occur. This project investigated the opportunity cost of reduced N and seeding rates at a range of sites with low, moderate and severe frost risk/ damage in the western and southern regions of Australia. We report (1) extensive trials (PA scale 10x30m) which examined the impacts of canopy management on changing frost severity, duration and damage and (2) intensive trials (small plot 10x1.8m; Nicol et al 2020) which evaluated synchronicity of crop development and frost.

Methods
Trial design, treatments and in season measurements
Large-scale (10 × 30m plots) trials were sown in frost prone paddocks across the western and southern regions of Australia in 2016 to 2018 and managed according to local grower practice (Table 1). Each trial was a factorial of two seeding rates and three nitrogen rates arranged in a split plot design with four replicates. Seeding rate was the main plot and nitrogen rate was the subplot. Seeding rate treatments consisted of a ‘low’ seeding rate (half the standard grower practice) and a ‘full’ seeding rate (farmer practice; Table 1). The treatments consisted of ~ half farmer N rate (N1; 6.5-20kg N/ha), an approximate farmer N rate (N2; 25-60kg N/ha), and a high N rate of 1.5 farmer practice (N3; 70-105kg N/ha).
To monitor the impact of crop canopy on frost severity and duration, unshielded air temperature was logged every 15 minutes between early stem elongation (Z31) and crop maturity (Z87) in each plot. Tiny Tag Plus 2 (TGP-4017) loggers with internal temperature probes were installed and maintained at canopy height over the course of the season. Establishment counts were done 10-14 days after sowing. Zadok scores were assessed weekly from ~Z45 to Z70 to estimate awn peep (Z49), heading date (Z55) and flowering date (Z65). Frost damage was estimated on 30 random heads sampled at Z85 on the outside florets only and excluding the terminal and basal spikelets. Harvest maturity cuts (0.5-0.6m^2) were taken at Z89 for each plot and processed to obtain grain yield and its components. Two harvest cuts (5-8m^2) were harvested with a small-plot research header.

Statistical analysis of frost severity, duration, damage and gross margin.

The total number of days the canopy was exposed to temperatures below -1 and -3°C between Z49 and Z85 was calculated. Frost severity was calculated by summing the min temperatures below zero across that period and taking the absolute value. As these are sums, the magnitude of any treatment differences reflects a combination of the number of frost events and the extent of the low temperature. To account for this multiplicative dependency, the duration and severity scores were Log10 transformed before analysis. Due to high spatially variability (local topography) in the Lubeck trial in 2016, this trial was omitted from temperature analysis. The variables, frost severity, duration, floret sterility, yield components and gross margin were analysed separately by applying a combined trials analysis approach in a linear mixed model framework. The treatment factors of seeding (‘half’, ‘full’), nitrogen level (N1, N2, N3) and sites were treated as fixed effects and all two- and three-way interaction factors were included. The interactions were tested using Wald-type tests (Kenward & Roger, 1997). Terms to account for the blocking structures of the trial designs were included in the random part of the model. All models were fitted with residual maximum likelihood (REML) (Patterson & Thompson, 1971) using ASReml-R package (Butler, 2018) in R computing environment (R Core Team 2019).

Table 1. Location and year of the extensive nitrogen trials (2016-2018).

Year	Trial	Site	Plotsize (m)	Seeding Rate applied (kg/ha)		Plant establishment (plants/m2)		Nitrogen Rate (kg/ha)			Variety	Previous Crop	Sowing Date	Starting Soil N**	Soil Type	GSR*** (mm)
				Half	Full	Half	Full	N1	N2	N3						
2016	ENA16COND2	Condobolin	18x37	15	30	40	55	6.5	25	90	Spitfire	Fallow	6th May	88	BRGR loam	440
	ENA16KULI6	Kulin	19x30	34	68	75	103	10	40	70	Mace	Canola	4th May	7	GR sandy loam	206
	ENA16LUBE3	Lubeck	12x30	40	80	89	164	5	55	105	Trojan	Canola	5th May	42	GR clay	400
	ENA16PING6	Pingrup	18x25	35	70	95	190	20	50	80	Mace	Barley	18th May	12.5	GR sandy loam duplex	279
2017	ENA17COND2	Condobolin	18x37	15	30	30	56	6.5	25	90	Lancer	Fallow	1st May	36	BRGR loam	128
	ENA17CORR6	Corrigin	14x30	35	70	84	132	10	40	70	Mace	Barley	19th May	26	GR gravel duplex	268
	ENA17MECK6	Meckering	12x30	35	70	80	127	15	45	75	Ninja	Pasture	20th June*	27	GR sandy gravel duplex	255
	ENA17MURT3	Murtoa	12x30	35	70	60	132	5	33	60	Scout	Lentils	8th June	31	GR clay	313
	ENA17WICK6	Wickepin	10x10	35	70	56	118	5	30	60	Sceptre	Canola	26th May	24	GRBR sandy loam duplex	266
2018	ENA18CORR6	Corrigin	14x30	35	70	74	117	10	40	70	Mace	Barley	15th May	48	GR sandy gravel duplex	243
	ENA18LONG3	Longerenong	12x30	40	80	61	132	6.5	60	105	Walup	Canola	9th May	113	Grey clay	159
	ENA18WICK6	Wickepin	10x10	35	70	83	144	15	35	65	Sceptre	Canola	31st May	30	GRBR sandy loam duplex	245

*Dry sown 28 May, **Total N, nitrate + ammonium kg/ha, 0-10cm western (WA) sandy soil types or 0-60cm eastern sites (NSW, Vic), ***GSR = growing season rainfall calculated as April to October.

Results

Only the main effects of seeding rate and nitrogen on yield components, maturity biomass, grain yield, grain quality and gross margin were significant (Table 2 & 3). Increasing seeding rate increased establishment in line with expectations (Table 1) and there was no effect of nitrogen on plant establishment (data not shown). There was no difference in phenology between seeding rate or nitrogen rate treatments at any of the sites based on weekly observations from stem elongation to after flowering, (Z31 to Z71). Where differences in frost damage were observed, it is likely to have been due to either very minor differences in crop development not detected by weekly observations or differences in frost exposure.

Frost severity and duration: Seeding rate and nitrogen

At seven of the 10 sites increasing seeding rate generally increased the severe temperatures of frost events between awn peep and late grain-fill (data not shown). Increasing seeding rate also increased the duration of the frost events (hours below 0, -1, -3 and -4°C). whereat some sites there was an interaction with nitrogen rate, although the effect was not consistent across sites. Figure 1 illustrates the main effect of increasing seeding rate on the hours below -1ºC (a) and -3ºC (b). The effect of seeding rate was greater at lower temperatures, i.e. -3ºC was greater than -1ºC. The effect of seeding rate on increasing frost duration was clearer at the ‘grower practice’ and above nitrogen treatments (N2 and N3). Increasing the nitrogen rate increased the severity and duration of frost events (Figure 1). In nine of the 10 trials, there was a consistent effect of nitrogen on duration below -1°C at both the ‘half’ and ‘full’ seeding rates. The exception was at Meckering in 2017 where higher nitrogen reduced frost duration at the ‘half’ seeding rate (data not shown). Generally, the plots spent longer below the -1°C threshold when they produced they greatest biomass at the ‘half’ seeding rate N3 treatment or the full seed rate and N2 or N3 (data not shown). Reducing seeding rate and nitrogen to half grower practice reduced the severity of the frosts by a small amount and increasing nitrogen to 1.5 grower practice increased it.

Increasing canopy biomass through nitrogen by seeding rate treatments was associated with an increase in frost severity and duration (Figure 1e). Within each trial, there was a consistent increase in the hours spent below -1ºC as biomass increased ($P < 0.001$), $\hat{\beta}=0.55$). For every unit increase in biomass (t/ha), the total time the canopy spent below -1ºC during the susceptible window (Z49-85) increased by ~33 mins. Anthesis biomass increased from ~4 to 8t/ha from the 'half' seeding rate with N1 through to the 'full' seeding rate and this ~4t/ha increase in biomass provided only a ~2hr 12min increase in the duration of the frosts for the whole susceptible window (Z49-85). Although statistically significant, this is a relatively small impact compared to the effect of stubble. In the work of Jenkinson et al (2017) a 4t/ha increase in stubble load at seeding increased subsequent frost duration during Z49-85 by 10-20hrs (@< -1°C) at York (2016), Corrigin (2016) and Cunderdin (2015). In summary, increasing biomass via the combination of higher seeding and higher nitrogen rates resulted in a small but consistent increase in frost severity and duration during the frost-susceptible window of Z49-85, however it's agronomically insignificant compared to the effect of stubble.

Frost damage, floret sterility, yield components on seeding rate and nitrogen

Seeding rate alone had no impact on frost duration and severity at any site. Reducing seeding rate to half the grower practice did not reduce floret sterility, anthesis (data not shown) or maturity biomass, harvest index, grain yield, grain quality (screenings and hectolitre data not shown), grain protein or gross income at 11 of the 12 sites (Table 2). Condobolin (2016) was the exception with higher seeding rate at this site delivering a slightly higher gross income (~$95/ha; Table 2, most likely due to the poorer establishment that resulted from a dry start/seedbed, which limited plant numbers at this site (~40 plants/m2; Table 1). More viable heads were observed at the higher seeding rate (Table 2) with grains per spike compensating for lower establishment (data not shown). While the results indicate there was generally no opportunity cost associated with reducing seeding rate, reduced weed competition and greater weed seed set was observed at most sites.

Across the trials, frost damage ranged from nil to ~ 60% sterility with no consistent response to nitrogen application at 11 of the 12 sites. The exception was at Corrigin in 2018 where the N3 treatment resulted in less sterility than the N1 and N2 treatments (Table 3), however this was not reflected in the other yield components measured. As expected, nitrogen increased biomass production and grain yield at most sites, with 10 of the 12 sites being N-responsive and delivering increased biomass at anthesis (data not shown) and maturity (Table 3). Lubeck in 2016 and Murtoa in 2017 on the grey vertosol soils were not N-responsive because they had just come out of a legume phase and had high background N (>30kg/ha N @ seeding) and adequate in-season mineralisation (1.4-1.6% organic carbon) (Table 1).

Conclusion

We examined the effects of halving seeding rate of wheat compared to farmer practice and increasing or decreasing N rate. These practices had an impact on biomass and grain yield and at some sites the duration of the frost susceptible period and severity of low temperatures increased in larger crops. We did not observe a significant increase in frost damage in larger crops, but gross margins increased. Growers need to maintain robust seeding rates for weed competition and be confident in maintaining local district practice for nitrogen.

References

Butler DG, Cullis BR, Gilmour AR, and Gogel BJ, (2018) ASReml-R 4 reference manual: mixed models for S language environments. Queensland Department of Primary Industries and Fisheries.

Kenward MG and Roger JH, (1997) Small sample inference for fixed effects from restricted maximum likelihood. Biometrics 53:983–997.

Patterson HD and Thompson R, (1971) Recovery of inter-block information when block sizes are unequal. Biometrika 58:545-554.

Nicol D et al, (2020) Nitrogen and density impacts on frost risk of wheat. GRDC Updates Perth 2020.

Rebbeck M, and Knell G, (2007) managing Frost Risk : A guide for Southern Australian grains. Ground Cover Direct.

Smith et al, (2017). Stubble management recommendations and limitations for frost prone landscapes. GRDC Crop Updates Perth 2017.

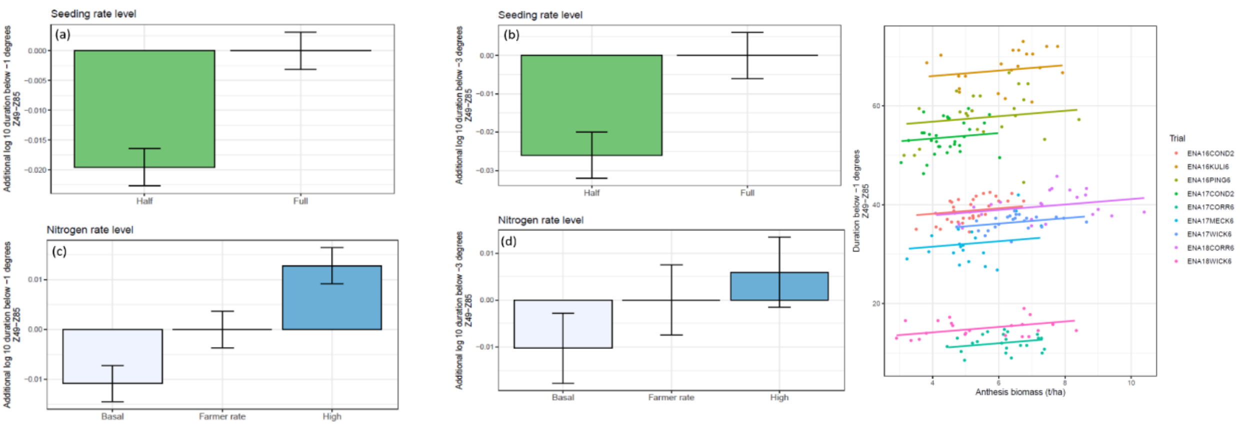
Table 2. Main effects of seeding rate ('half' grower practice and 'full' grower practice) on frost damage, grain yield components and gross margin in extensive nitrogen trials 2016-2018. Significant differences between seeding rate within each trial indicated by different letters (p<0.05). Frost damage rated as nil (white fill), low (light blue fill), moderate (medium-blue fill) or severe (dark-blue fill) based on floret sterility, harvest index and visual observations from the field.

Trial	Flowering (Z65)	Floret Sterility (0-1.0 proportion)		Maturity Biomass (t/ha)		Viable heads (Number/m^2)		Harvest Index		Grain Yield (t/ha)		Grain Protein (%)		Gross margin ($/ha)*	
		Half	Full	Half	Full	Half	Full	Half	Full	Half	Full	Half	Full	Half	Full
ENA16KULI6	15th Sept	0.59	0.58	8.5	8.5	550	610	0.16	0.13	1.7	1.6	11.2	11.1	365	330
ENA16PING6	25th Sept	0.47	0.53	8.4	8.7	520a	615b	0.26	0.22	2.1	1.9	10.4	10.3	265**	235**
ENA17MURT3	27th Oct	0.00	0.00	10.4	11.3	390a	500b	0.23	0.25	2.1	2.2	13.5a	14b	360	400
ENA18CORR6	30th Sep***	0.47	0.57	8	7.2	355	385	0.25	0.23	1.9	1.8	10.3	10.3	670	610
ENA16COND2	13th Sept	0.25	0.29	7.6	8.2	220	250	0.44	0.43	3.0	3.3	13.2	13.4	865a	960b
ENA17COND2	30th Sept****	0.08	0.10	5.2	5.3	165	190	0.39	0.36	1.3	1.4	12.7	12.5	445	460
ENA18WICK6	5th Oct	0.14	0.13	8.1	8.3	365	420	0.35	0.35	2.7	2.8	9	8.6	910	955
ENA17WICK6	30th Sept	0.10	0.09	6.9	7.2	120	130	0.36	0.35	4.0	4.1	7.5	8.0	970	985
ENA17CORR6	12th Sept	0.07	0.08	8.4	8.1	205	220	0.47	0.48	3.4	3.5	7.7	7.6	825	830
ENA16LUBE3	12th Oct	0.04	0.03	16.1	15.1	300a	385b	0.43	0.41	6.3	6.4	9.3b	8.6a	1270	1280
ENA17MECK6	25th Sept	0.04	0.05	7.8	8.1	250a	295b	0.46	0.45	2.7	2.9	8.4	8.1	700	730
ENA18LONG3	11th Oct	-	-	-	-	-	-	-	-			-	-	-	-
Average		0.20	0.22	8.67	8.73	313	364	0.34	0.33	2.8	2.9	10.0	10.0	738	754

Table 3. Main effects of nitrogen rate (N1 ~ half grower practice, N2 = grower practice and N3 = 1.5 grower practice) on frost damage, grain yield components and gross margin on extensive nitrogen trials 2016-2018. Significant differences between seeding rate within each trial indicated by different letters (p<0.05). Frost damage rated as nil (white fill), low (light blue fill), moderate (medium-blue fill) or severe (dark-blue fill) based on floret sterility, harvest index and field observations.

Trial	Flowering (Z65)	Floret Sterility (0-1.0 proportion)			Maturity Biomass (t/ha)			Viable heads (Number/m2)			Harvest Index			Grain Yield (t/ha)			Grain Protein (%)			Gross margin ($/ha)*		
		N1	N2	N3	N1	N2	N3	N1	N2	N3	N1	N2	N3	N1	N2	N3	N1	N2	N3	N1	N2	N3
ENA16KULI6	15th Sept	0.56	0.61	0.60	7.6a	8.8b	9.3b	520a	540a	680b	0.13	0.16	0.14	1.5a	1.5a	1.8b	10.7a	11.3b	11.4b	325	325	395
ENA16PING6	25th Sept	0.46	0.52	0.53	7.6a	8.7b	9.5b	500a	570ab	640b	0.25	0.23	0.22	1.8a	2.0ab	2.2b	9.6a	10.4b	10.9b	260**	240**	255**
ENA17MURT3	27th Oct	0.00	0.00	0.00	10.7	10.9	10.9	435	450	445	0.26	0.24	0.22	2.0	2.0	2.5	14.0	13.8	13.6	400b	315a**	420b
ENA18CORR6	30th Sept***	0.56	0.57	0.43	6.5a	7.8b	8.8c	325a	380ab	405b	0.24	0.23	0.24	1.5a	1.8b	2.2C	9.9a	10.6b	10.5b	530a	645b	745c
ENA16COND2	13th Sept	0.27	0.26	0.28	7.5a	7.3a	8.9b	225	225	255	0.44	0.43	0.43	3.1a	3.0a	3.4b	13.1	13.0	13.7	910	880	945
ENA17COND2	30th Sept****	0.07	0.09	0.11	4.9a	5.1a	5.8b	165a	175ab	200b	0.38	0.37	0.37	1.3	1.3	1.5	12.4a	12.2a	13.2b	445	460	455
ENA18WICK6	5th Oct	0.15	0.12	0.15	8.0a	7.9a	8.7b	390	380	405	0.35	0.34	0.36	2.7	2.8	2.8	8.5	8.8	9.0	950	940	910
ENA17WICK6	30th Sept	0.11	0.10	0.08	5.9a	6.5ab	7.0b	114	128	136	0.34	0.35	0.37	3.6a	4.2ab	4.3b	7.9	7.6	7.8	905a	1005b	1020b
ENA17CORR6	12th Sept	0.07	0.07	0.08	7.1a	8.4b	9.5c	190a	220ab	230b	0.47	0.47	0.47	2.8a	3.5b	4.1c	7.3a	7.5ab	8b	695a	825b	965c
ENA16LUBE3	12th Oct	0.03	0.03	0.03	15.5	15.2	16.1	340	330	345	0.42	0.41	0.43	6.0	6.3	6.8	8.5a	8.9ab	9.3b	1225a	1280ab	1325b
ENA17MECK6	25th Sept	0.04	0.04	0.05	7.7a	7.4a	8.8b	265	260	290	0.46	0.47	0.43	2.6a	2.8ab	3.1c	8.2	8.2	8.3	700a	700a	745b
ENA18LONG3	11th Oct	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average		0.23	0.24	0.23	8.7	9.2	10.1	324	344	378	0.33	0.33	0.32	2.6	2.8	3.2	10.0	10.2	10.5	668	692	744

*Gross margin was calculated on each plot as Gross Income (yield x $/t) minus seed and nitrogen cost for each season based on local port April 20 fertiliser and December 20 grain prices and state classifications ** severely grain-frosted and price based on a $20-30 discount from FED1 for un-deliverable grain. ***Delayed as head frosted at Z58 and based on late unfrosted tillers, ****Delayed as



based on re-tillered canopy after sever stem elongation frost damage in late August.

Figure 1. Predicted mean (Log_{10}) for additional hours spent below -1°C (a,c) and -3°C (b,d) compared to the control, for the crop development stages Z49 to Z85 in relation to seeding (a,b) and nitrogen (b,c) rates. Control treatment was full seeding rate with farmer-standard nitrogen rate. Error bars +/- LSD0.05 for comparisons within trials. (e)Fitted curves by trial for a regression of hours below -1°C for the crop development stages Z49 to Z85 against anthesis biomass (t/ha) for the southern (NSW, Vic) and western (WA) region trials, Significant at P< 0.001 with slope 0.55 with different intercepts for each trial.