Manipulation of sowing time and variety to manage abiotic stress risk and maximise yield in lentil and faba bean

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Abstract
Lentil and faba bean production is constrained by extreme temperatures and drought. Crop species, variety and sowing time are three important management options for limiting the impact of these stresses. We measured phenology and relative grain yield in 10 lentil and 10 faba bean varieties over three seasons (2016 - 2018) and three regions in southern Australia; Hart and Roseworthy in the mid north, Minnipa on the Eyre Peninsula and Bool Lagoon and Conmurra in the South East. Within each location we used six times of sowing, spaced two weeks apart beginning mid-April. For both crops across locations, time to flowering and pod set declined linearly with sowing date. Similarly and across locations and sowing times, flowering was advanced at 3 d d^{-1} in faba bean and 5 d d^{-1} in lentil. Yield trends varied with species and location, but delaying sowing generally reduced yield. For every ten days delay in sowing past April 20th, faba bean lost 7% and lentil 5% of maximum yield; for the conditions in these trials sowing before the middle of may was the best strategy. This data set will be used to model risk and to guide management decisions.

Key Words
Crop modelling, phenology, risk management, stress, yield

Introduction
Lentil and faba bean are two important pulse crops with growing interest from farmers in low rainfall areas of southern Australia. Interest is primarily driven by encouraging (albeit fluctuating) price trends, in addition to the rotational benefits of pulses. However, these crops are prone to yield loss due to frost and combination of water and heat stress at critical growth stages (Lake and Sadras, 2014; Delahunty et al., 2018).

Maximising yield and minimising risk can be achieved by selecting the best variety and sowing time combination to fit the environment and allow flowering and particularly pod set (the critical yield period of pulses) to occur with a minimised risk of extreme temperatures and water stress. Early season pod set increases risk of frost damage, and reduces risk of heat and drought yield losses, hence the importance of managing this trade-off.

The objective of this study was to analyse the effect of sowing date and variety on the phenology and relative grain yield of lentil and faba bean in South Australian cropping environments. The data will also be used to improve our modelling capabilities, particularly for lentil.

Methods
Field trials were located in three regions of South Australia; on the Eyre Peninsula at Minnipa (2016, 2017 and 2018, -32.8, 135.2), the Mid North at Hart (2016, -33.8, 138.5) and Roseworthy (2017 and 2018, -34.5, 138.9) and the South East at Bool Lagoon (2016 and 2017, -37.2, 140.7) and Conmurra (2018, -37.1, 140.2). The trials combined six sowing dates spaced every two weeks from 20th April to 9th of July. Ten common lines of each species were chosen in consultation with breeders and industry experts (Table 1).

Three replications were sown of crop × variety × sowing time at each location. Plots were sown by hand in a split-plot design with sowing dates allocated to the main plot and varieties randomized within each subplot. Plot size was 1 m^2 and consisted of three rows, 0.27 m apart. Phosphorus was applied as 80 kg ha^{-1} of MAP at sowing. When necessary, crops were irrigated (at least 10mm) to ensure even germination and emergence.

Phenology was measured twice weekly, and the date when 50% of plants within the central row had reached: emergence, flowering, pod emergence, end of flowering and maturity was recorded. Grain yield was measured at Minnipa (2016, 2017 and 2018), Roseworthy (2017 and 2018) and Conmurra (2018 – faba bean only), in a sample of 0.5 m length from the central row of all plots. Samples were dried at 70 ^{o}C until constant weight and then grains were separated from the pods, cleaned, counted and weighed. Owing to the small size of plots and sample, yield data are only used to suggest general relative trends.

Results

Weather

The main difference between locations was rainfall, with crops affected by drought at Minnipa (2017 and 2018) and waterlogging at Bool Lagoon (2016 and 2017). Some environments experienced some level of frost such as Roseworthy 2018 (Figure 1), but the most influential stress was the combined effect of heat and water (see Minnipa 2017, Figure 1).

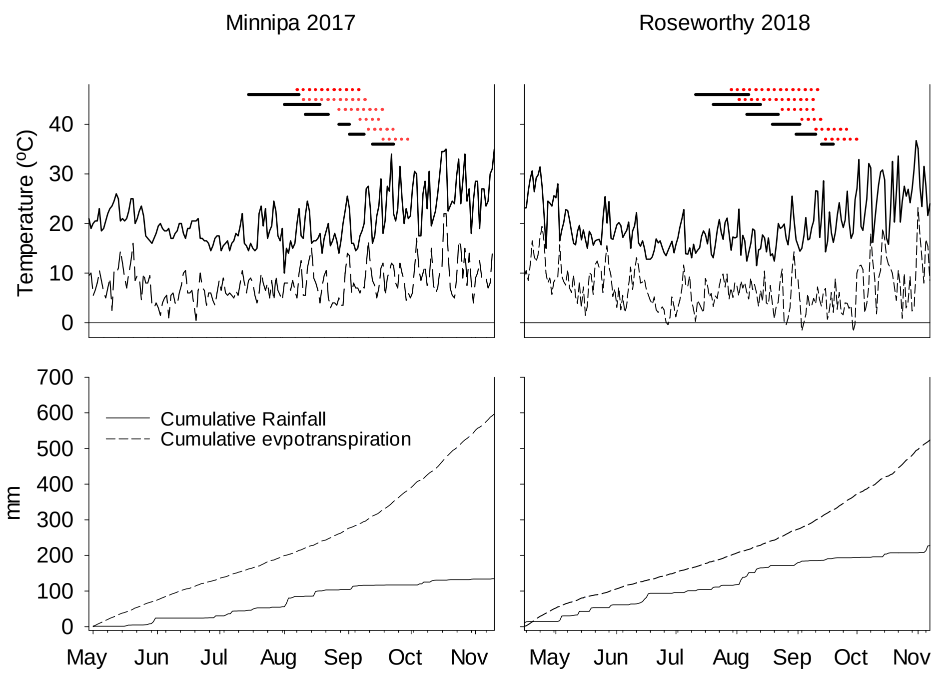

Figure 1. Temperature (maximum and minimum), rainfall, evapotranspiration and flowering window for the 10 lentil (flowering window is the red dashed lines) and 10 faba bean (flowering window is the black solid lines) lines sown across Minnipa in 2017 and Roseworthy in 2018. Sowing times were fortnightly beginning May 1 (Minnipa 2017) and April 27 (Roseworthy 2018).

The various growing conditions generally reflect the historical records (past 30 years) for rainfall, and temperatures. Minnipa is a dry location with average annual rainfall of 326 mm, Roseworthy (431 mm) and Hart (460 mm) are intermediate, while Bool Lagoon (580 mm) and Conmurra (650mm) are higher rainfall regions. Actual temperatures in the flowering window (indicated for each sowing date by the black solid lines and red dashed lines in the top panels) are illustrated in Figure 1 (July through October); Minnipa is the lowest risk for frost with 0.03 days where temperatures fall below 0 ^{o}C, Roseworthy and Bool Lagoon both have 2, while Hart is higher risk with 4 days based on long term averages. For high temperatures (above 30 ^{o}C) Minnipa is the greatest risk with 10 days per year, Roseworthy has 5, Hart 4 and Bool Lagoon 1.5.

Table 1. Variation in days (d) from sowing to 50% flowering time in faba bean and lentil varieties.

Faba Bean	Mean	Minimum	Maximum	Lentil	Mean	Minimum	Maximum
AF03001-1	76	51	117	PBABlitz	93	71	138
Fiord	78	55	93	CIPAL901	95	71	138
AF009169	80	57	146	PBAGiant	97	72	142
Farah	81	57	125	PBAJumbo2	98	71	146
PBAZahra	84	59	113	CIPAL1301	99	76	149
PBARana	85	60	110	PBAHallmarkXT	100	71	150
Nura	85	61	115	PBAHurricaneXT	101	77	150
PBASamira	86	60	116	Matilda	103	73	149
Aquadulce	88	59	122	Nugget	104	76	150
Icarus	98	66	133	Northfield	109	82	170

Yield and phenology

The trends in phenology were consistent across environments with time to flowering and podding decreasing with delayed sowing (Table 1, Figure 1). Variety and time of sowing both had significant effects ($P < 0.001$) on time to flowering and podding in lentil but the interaction was not significant; for faba bean all three sources of variation were significant ($P < 0.001$). The negative relationship between sowing date and days to flowering and podding was similar between species. Flowering was delayed at 3 d d^{-1} in faba bean and 5 d d^{-1} in lentil.

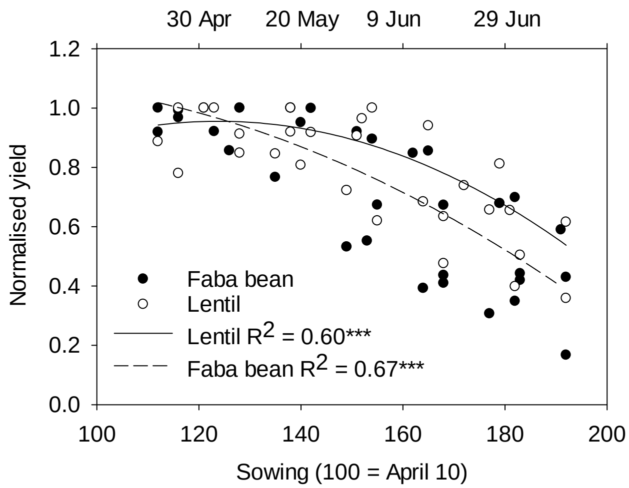

Figure 2. Yield penalty as a function of sowing delay from April 22. Yield is a proportion of attainable yield for each location × season combination. There were five lentil and six faba bean location × season combinations each with six times of sowing. Lines are polynomial regressions.

Yield declined with delayed sowing when locations were pooled (Figure 2). However the relationship varied between species, years and locations. For lentil, there was a significant effect of environment and variety (both $P < 0.0001$) as well as a significant interaction ($P = 0.01$); for faba bean environment and variety both had a significant effect ($P < 0.001$) with no interaction. The patterns of yield loss for faba bean and lentil fit three general trends (Figure 3). Trend one is a linear reduction, while trend two is a two phased linear reduction while the third trend shows a linear increase and then a reduction. Table 2 presents the yield gain/loss rates associated with these trends presented in Figure 3 for lentil and faba bean in the different environments.

Table 2. Parameters for the yield loss functions associated with delayed sowing. Rates in percent per day.

Crop	Environment	Type	Inflection point (Julian day)	Date (inflection)	rate (gain)	rate (loss) 1	rate (loss) 2	R^2
Lentil	Minnipa 2017	1				-0.0077 ± 0.0012		0.88
	Minnipa 2018	1				-0.0097 ± 0.0005		0.99
	Roseworthy 2017	2	173 ± 8.15	22nd June		-0.0022 ± 0.0014	-0.0144 ± 0.0006	0.88
	Roseworthy 2018	3	153 ± 5.63	2nd June	0.0053 ± 0.0001	-0.0170 ± 0.0029		0.84
	Minnipa 2016	3	152 ± 20.34	1st June	0.0010 ± 0.0019	-0.0108 ± 0.0005		0.82
Faba bean	Minnipa 2017	1				-0.0115 ± 0.0011		0.96
	Minnipa 2018	3	133 ± 8.32	13th May	0.0027 ± 0.000007	-0.0149 ± 0.0016		0.92
	Roseworthy 2017	2	172 ± 1.19	21st June		-0.0054 ± 0.0002	-0.0192 ± 0.00001	0.99
	Roseworthy 2018	3	148 ± 0.49	28th May	0.0002 ± 0.0001	-0.0016 ± 0.0002		0.99
	Minnipa 2016	3	144 ± 4.38	24th May	0.0032 ± 0.0007	-0.0087 ± 0.0005		0.97

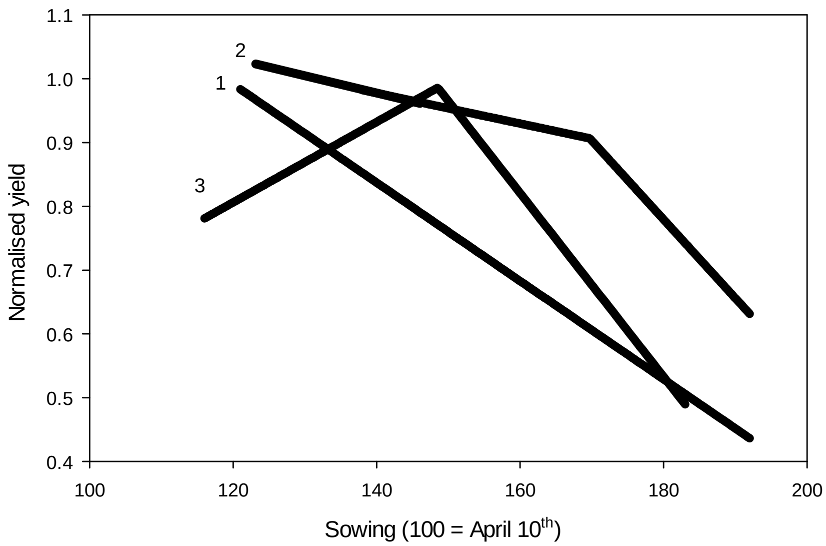

Figure 3. A representation of the three types of yield response to delayed sowing time common to lentil and faba bean. Type 1 fits a linear model while type 2 and 3 are piecewise two segment linear models.

Trend type 3 (Fig 3) was the most common, indicating a tradeoff between early sowing favouring yield potential, and frost risk and drought. At Roseworthy 2018 for example early sowing led to a significant yield penalty with first and second times of sowing yielding significantly less than the fourth ($P < 0.05$). This yield loss was due to excessive canopy growth with low harvest index; canopy growth declined and harvest index increased with later sowing dates. The rainfall patterns resulted in the higher biomass canopies of early sowing suffering from water stress later in the season and failing to realise potential yield (Erskine and El Ashkar, 1993; Zeleke and Nendel, 2019).

Conclusion

Phenology of faba bean and lentil crops were significantly affected by sowing time under South Australia growing environments, where flowering advanced at 3 d d^{-1} in faba bean and 5 d d^{-1} in lentil commencing the 22 April (Figure 1) . In 90% of cases this reduction in vegetative phase caused reduced biomass and yield. Optimal sowing tended to be as early as possible in very dry environments, while in other environments there was limited impact on yield until sowing was delayed past the middle of May. For every ten days delay in sowing past April 20th, faba bean lost 7% and lentil 5% of maximum yield.

However, in the absence of severe frost, sowing before the middle of May will be more likely to provide the maximum yield for the location whilst allowing some flexibility in the system for other factors such as soil water, weed and disease control. Overall, these data set will be used to model risk associated with frost and high temperature and to guide management decisions for pulse production in south Australian growing environments.

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